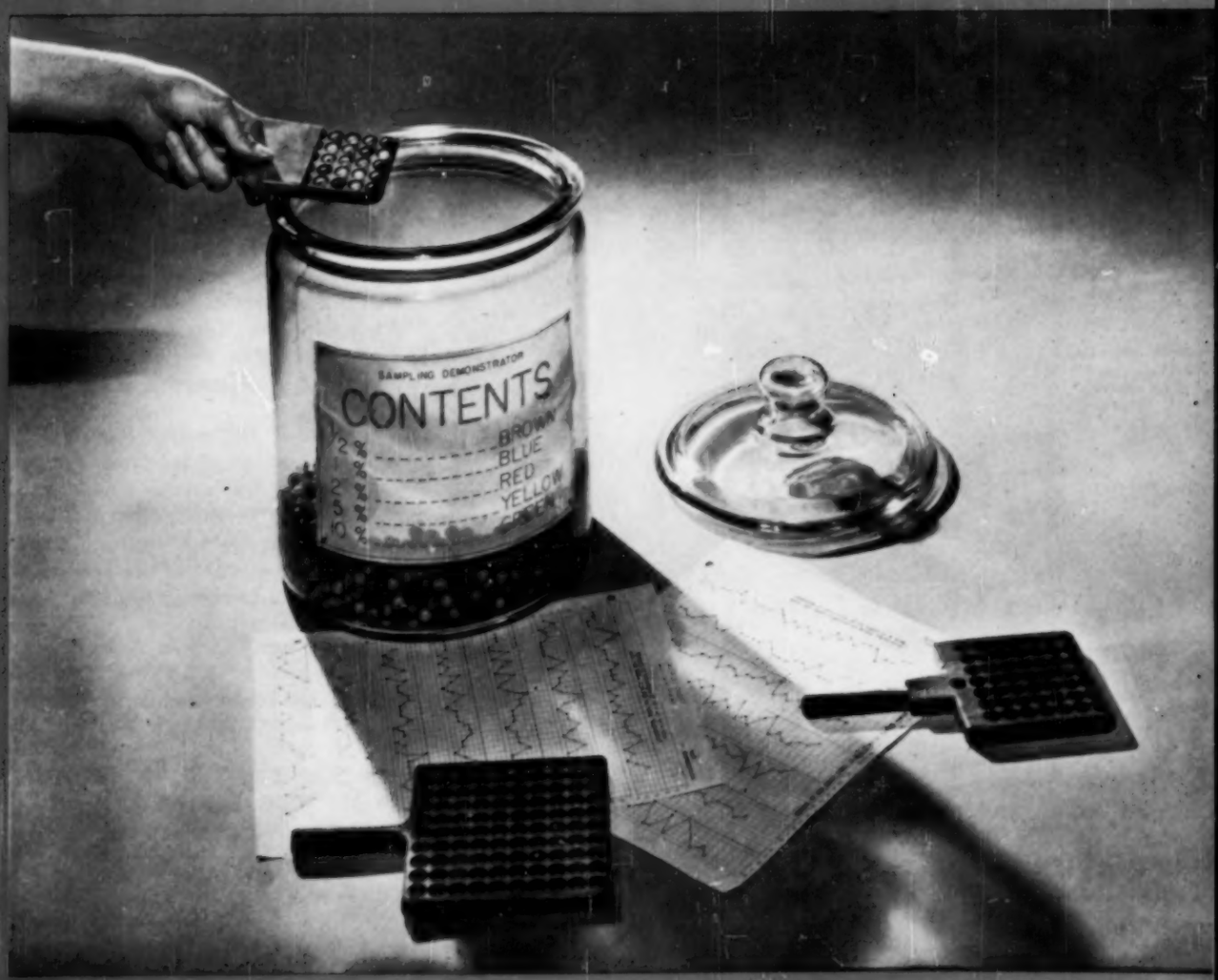
Industrial
QUALITY CONTROL

NOVEMBER, 1950 VOL. VII NO. 3



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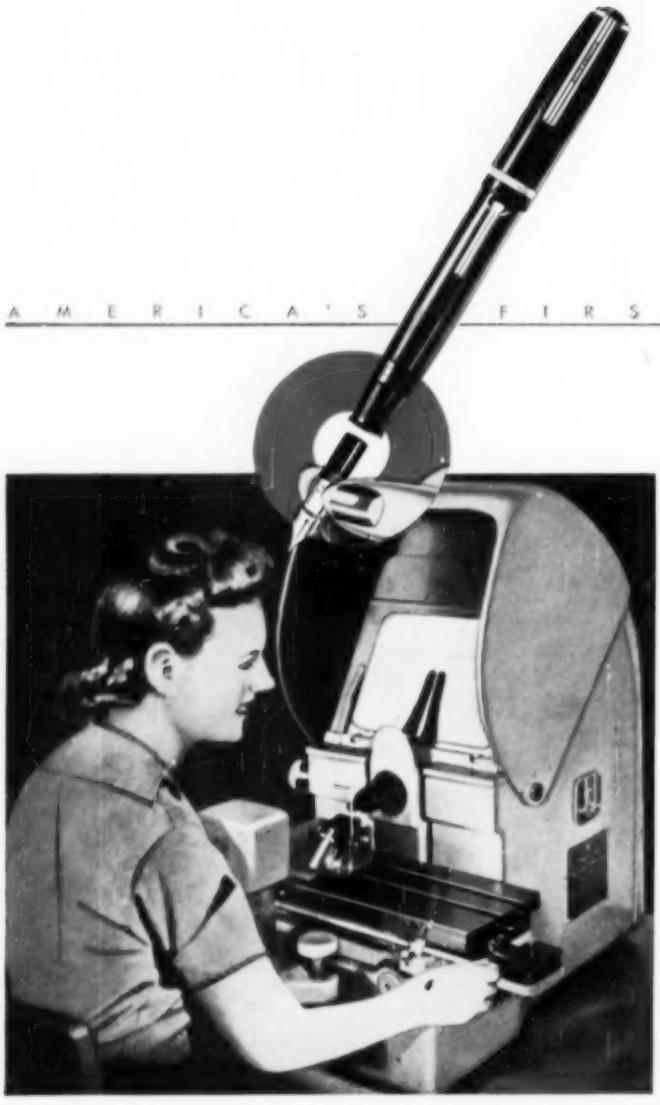

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A UNIVERSAL SAMPLING DEMONSTRATOR

W. P. KOECHEL

Tung-Sol Lamp Works, Inc.

The cover photograph on this issue illustrates a versatile combination of *jar, beads,* and *paddles* for attribute sampling demonstrations.

Jar. The jar is transparent and therefore dramatically exposes the beads.

Beads. There is a total of 2000 beads of five different colors in the jar so distributed that each color represents a different "process average." Thus there are ½% brown beads, 1% blue, etc. By announcing ahead of time which color bead is going to represent "defectives," it is possible to demonstrate the results of sampling from many different process averages at a moment's notice. Beads are 10 mm wood beads.

Paddles. The paddles are three in number, and slide covers are available for them so that various combinations of holes can be exposed. If, for example, we want to demonstrate the fallacy of detecting a 1% condition with samples of 5, we could use the 25-hole paddle with 5 holes exposed and then count any blue beads scooped up as "defective."

As a matter of interest, the curves in the picture represent the results of selecting a sample size of 50 and counting any blue beads as defective. The plots represent the number of blue beads found in each "scoop" of 50.

CHANGES AND CORRECTIONS FOR THE HAMILTON STANDARD LOT PLOT PAPER, JULY 1950, IQC, pp. 15-34

1. Page 18, column one, under III. "How to Handle Lot Plots": insert "see Plate I."
2. Page 18, column three, line ten from top: Change parenthetical expression to read "(see illustration in Plate I for Type 9)."
3. Page 18, column three, line eleven from top: Change sentence to read "Proceed as per last four sentences of (5) above at complete end if necessary."
4. Page 21, column three, line eight of Section D: Delete the words "Table B and Chart C$_1$ or Chart C$_2$" and replace these deleted words by the single symbol "$\bar{R}$".
5. Page 29, column two, line three of bottom paragraph: Change the phrase in parentheses to read "Lot Plot or attributes."

Industrial Quality Control

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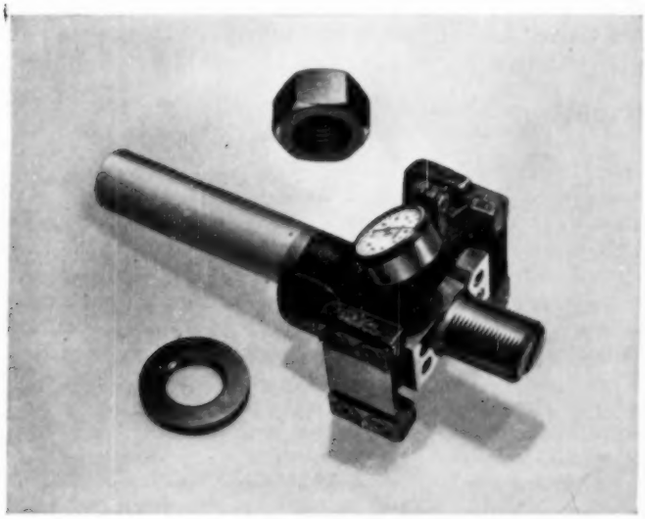
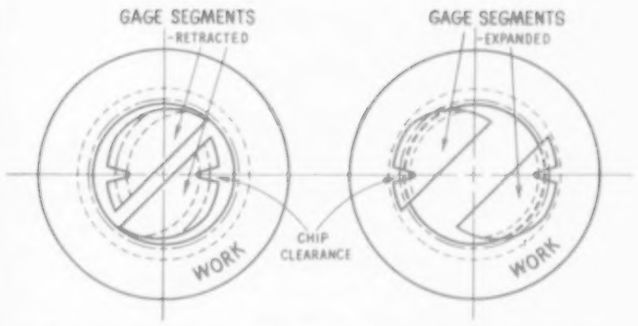
The new Bryant Internal Thread Gage will check parts 4 to 5 times faster!





Plug segments are collapsed so gage may be inserted or withdrawn without threading.

Plug segments are expanded to give full length contact on all the threads.

The new Bryant internal thread gage is based on the principle of a split plug gage. The plug segments are collapsed by a thumb lever and inserted into the threaded hole. When the thumb lever is released, the plug segments expand to contact the internal threads in the parts being inspected.

This new gage is portable, therefore, threads may be checked while the part is chucked in a machine, and it offers extra convenience when inspecting threads in large, heavy casting that cannot be moved conveniently.

The Bryant gage is designed to give one accumulated reading of P. D., form and lead on the dial indicator. For the first time it is now possible to sort parts into known classifications for fit (assemble-ability). This gage is used for the inspection of internal threads in a range from 5/16" to 1" diameter. Interchangeable segments are easily attached to the gage to cover a wide range of thread sizes. These segments are made to the same tolerances in P. D., lead, and form as a Class "W" Master. The life of the segments is lengthened by the fact that the gage does not have to be screwed into or out of the threaded hole – a partial turn gives a full reading on all the elements of all the threads.

Actual tests show that the Bryant portable internal thread gage will check parts four to five times faster than the standard plug gage!

MAIL THE COUPON FOR FURTHER INFORMATION

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Please send me complete details on the New Bryant Portable Thread Gage.

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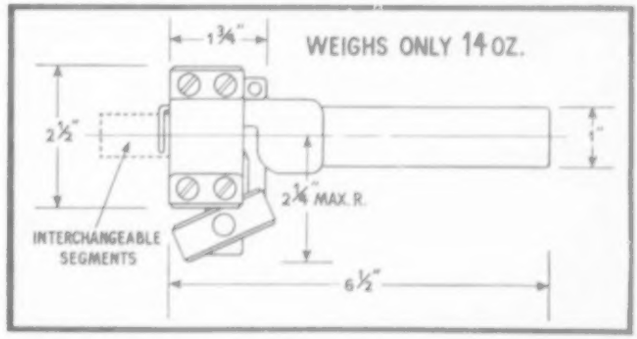

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SPRINGFIELD, VERMONT, U. S. A.

Ford's Interest in Statistical Quality Control

WM. H. SMITH
Manager, Analysis Department
Quality Control - Manufacturing Staff

C. R. BURDICK
Supervisor, Chart Section, Analysis Department
Quality Control - Manufacturing Staff

Ford Motor Company

FORD'S CONCEPT OF QUALITY

In talking of Ford's interest in Statistical Quality Control, we find it necessary to go back and reconstruct some of the thinking and reasoning that is responsible for our interest. This involves a consideration of "quality" in a general sense, and its relationship to other characteristics of a manufacturing organization.

Every product possesses quality in some degree. The greater the degree of quality the higher the demand for that product. This fact has been expressed very well in the slogan, "Quality and Demand Go Hand-in-Hand." We know that our sales, and hence the security of our Company and its employees, are dependent upon quality. Upon that basis has been founded the entire Ford Motor Company Quality Improvement Program.

Product quality from the consumer's viewpoint has been very aptly described as "that characteristic which distinguishes the product of one manufacturer from that of others in the same price class." If, for instance, we had a choice between two similar products we would very likely examine each of them for such things as smoothness of finish, quietness of operation, neatness of workmanship, nicety of detail, and other characteristics. Naturally we would choose the one that was smoother, quieter, neater and more detailed. We would say that it was of a higher quality than the other. And if we had an even wider choice, we would choose the product with the highest quality.

It's natural for all of us to want quality in the things we buy. And we don't want just plain quality—we want the very best quality obtainable within our means. In other words, as consumers we are quality conscious. We look for quality and buy quality wherever possible. The manufacturer who doesn't meet our quality requirements just doesn't get our business.

Now, if we look at this term "quality" from the manufacturer's side of the fence, we see that we've got to produce quality or we won't have customer acceptance of our product.

The automotive industry's number one problem today is not only one of meeting the price and quality demands of an increasingly exacting and shrewd buying public, but is also a problem of foreseeing and providing for these demands well in advance. Product quality has often been described from the manufacturer's viewpoint as an intangible thing which defies many of the down-to-earth practices of shop experience. Yet examination at the Ford Motor Company has proven to us that product quality is tangible and definable—that it has substance—that it can be measured and controlled—that it can be planned for and attained.

Quality Control then would apparently be the mere mechanics of controlling product quality — the simple measuring of parts. However, closer study reveals that mere mechanical control is not enough. Accurate tools, modern equipment, and precisely developed methods are ineffective unless the people in our organization have the craftsman's urge to build a product of the highest quality. Therefore, the Ford Motor Company defines Quality Control as a management philosophy which must be generated at the top and promoted throughout all levels of our entire organization by constantly selling the principles of craftsmanship and pride of performance to our people.

PROMOTING QUALITY CONSCIOUSNESS

In a Company as large as Ford this is a tremendous undertaking. We have within the Ford Motor Company approximately 137,000 employees. This is exclusive of the infinite number of people in our vendors' plants which has been estimated at upwards of 500,000. Our approach to them has been of necessity a mass promotion. We have used every psychological angle in the book. But above all we have treated them like people should be treated—with liberal praise for a job well done, and with patience, tolerance and help when they needed it. The results of such a program are inevitable. Good personnel morale and quality performance are cast in the same die. To have one you must have the other.

The first of our promotional programs was a poster campaign. This campaign was designed to bring the importance of quality performance to the individual employee in terms of job security, pride of performance, and cooperative effort. The posters are displayed in every department in the Ford Motor Company. In addition, a great many of our vendors display the same posters in their plants. Interest in our program is especially good. We know that it has played a big part in making our people quality minded. One poster in particular is associated with a humorous incident in one of our Purchasing Offices. One of our vendors had apparently taken a gamble on quality. He was called in by the buyer to explain his lapse from normal performance. At the completion of his explanation his eye fell on the poster displayed in the Purchasing Office which had the caption "Don't Gamble with Quality." Very quietly, he wrote at the bottom of it the word "Amen."

Shortly after the start of the poster campaign we embarked upon a quality slogan contest. This contest was open to every Ford Motor Company hourly-rated employee. It was designed to stimulate quality thinking on the part of the individual. Participation was extremely

good. 13,000 slogans were submitted and judged. Without exception they were all very good and showed the results of a lot of original thinking. The judging of the entries was a tough job. However, the final winner was John Hislop of the Chester Plant. John received a new Ford car as first prize for his entry, "Quality and Demand Go Hand-in-Hand."

We also publish monthly the "Quality Control News". It was our original intention to circulate the paper only to the Quality Control supervisory personnel in our various plants, but the general interest in this paper has been so great that we are currently circulating nearly 10,000 copies. The purposes of the "News" are many. Among them we can list: to inform all Quality Control personnel of new developments; to give credit for achievements; to announce coming events.

On November 8, 1949, a Quality Control Exhibition was held in the Detroit Masonic Temple. This show was the promotional highlight of 1949. More than 700 Ford Motor Company and vendor people viewed its displays. This exhibition showed some of the outstanding quality improvements made in our products to assure the building of an even better finished product in the future.

We are currently investigating the possibility of forming an award system similar to the Army E plan which operated during the war. The purpose of this plan would be to give recognition in plants which achieve outstanding quality performance. Recently we completed another quality promotional endeavor—a Quality Queen contest. Geared to stimulate quality thinking on a nation-wide, family basis, this contest was open to hourly-rated female employees, and the immediate families of all hourly-rated Ford workers. The contest started on April 10 and culminated with the crowning of the Quality Queen at a coronation celebration in Detroit on October 18. The Queen, among other prizes, received a Ford V-8 Convertible and a 3-day all expense round-trip to New York City. Her Court of Honor, composed of the four runners-up enjoyed other fine awards.

These are some of the promotional efforts we have used. The future will bring forth many more.

MODERN METHODS FOR QUALITY CONTROL

During the last 20 years the rapid developments in the automotive industry have been paralleled by equally rapid improvements in machines and equipment. This has meant the continual refinement of quality standards; higher degrees of precision in both workmanship and machines; and more accurate methods of gaging and controlling product quality. New tools and inspection gages have been developed.

Another new note in the Ford picture is the application of statistical methods to the control of product quality. In the past we have achieved a reliable degree of quality through the use of normal inspection methods, but these methods are now recognized to have certain limitations. They are like the story of the medical student and the professor. The student, in reply to a question, had prescribed a treatment for his imaginary patient. A little later he got up and said, "Professor, if I may, I would like to change my answer to that last question." "Too late," replied the professor, "your patient has been dead five minutes." It is the same with inspection. Only after the defective parts have been made is the mistake discovered and then it is too late. Inspection, as we have known it in the past, has been nothing more than a post-mortem operation, the primary purpose of which has been to sort the good parts from the bad. However, it is not our intention to compare Statistical Quality Control with the demerits of a departing inspection system but rather to show what Ford has done with Statistical Quality Control and what Ford intends to do in the future.

INSTALLING SQC AT FORD'S

First of all we recognized in Statistical Quality Control a tool which would give us the economical benefits of controlled operations, and at the same time give our customers better products, products not simply better than the rest, but products better than the *BEST*. We want to eliminate any possibility of the type of customer shown in Figure 1.

We are also aware, however, that Statistical Quality Control by itself is not a cure-all. To be successful it needs the support and cooperation of many other operations. Accordingly the Quality Control organization was set up in the following manner. There are four departments: Quality Analysis, Standards and Methods, Quality Laboratory, and Administrative. These departments are the coordinators of our quality organization and have functional supervision over similar departments in each of the five operating divisions. Statistical Quality Control is a function of the Quality Analysis Department.

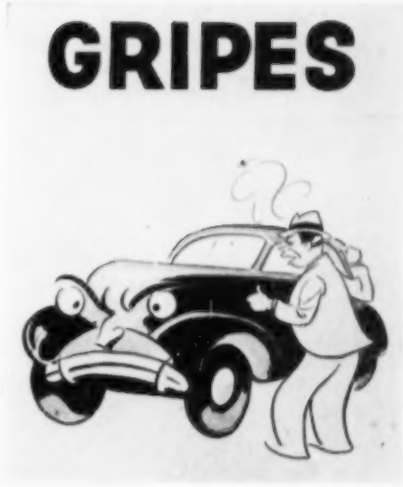


Figure 1.

The adoption of the statistical method for controlling product quality was a very vital decision—it had to envisage the vast reeducation of our employees. The common error is often made of associating practical Statistical Quality Control with highly theoretical mathematics. Even today industry carries many non-believers who have been frightened by these mathematical scarecrows. Recognizing the likelihood of these false conceptions the Ford Motor Company set out to remove the complex scarecrows and embarked upon a simplified and extensive educational program for our shop people. Our first job was to sell Statistical Quality Control.

Our Training Department, in conjunction with the Quality Control organization, developed several training courses suitable for the instruction of both hourly personnel and management. It has been proven beyond doubt that the average inspector and production man can readily assimilate, understand, and apply the principles of Statistical Quality Control. It is equally essential, of course, for management to take full cognizance of the new methods, and for this reason all of

Figure 2—**Typical Quality Control Chart Used by Ford.**

Figure 3—**Voltage Regulator Assembly Line at the Ypsilanti Plant. Note the extensive use of control charts.**

Figure 4—**Instrument Cluster Assembly at the Manchester Plant. Here again the control chart is visible to all operators.**

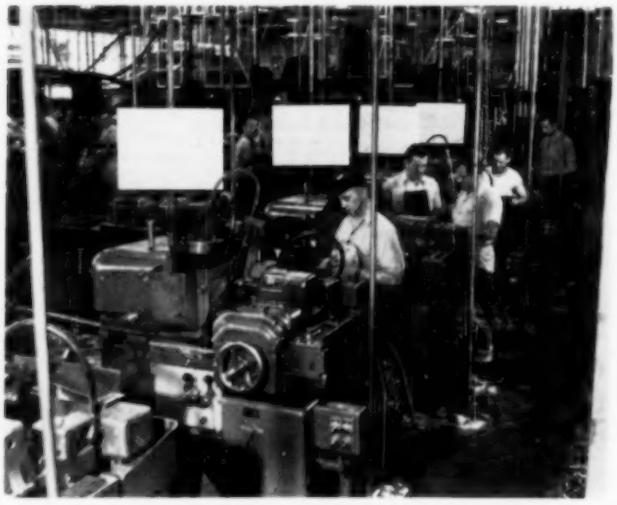


Figure 5—**Universal Joint Parts at the Mound Road Plant. Notice a control chart mounted on each individual machine.**

our inspection and production supervisors are required to take training. This training, by the way, is not confined to the Detroit area, but covers all Ford Locations in the United States. In addition, training material has recently been forwarded to our International activities.

Our next step, obviously, was the application of Statistical Quality Control to actual operations. This was quite an undertaking. We went about it in this way. Staff men, thoroughly experienced in the use of Statistical Quality Control, went into the various plants and assisted the local management with initial applications. Then local management took over and expanded statistical applications within their own organizations. It was like starting a grass fire. We touched it off at many points. In some spots enthusiasm blazed up rapidly and in others the fire was slow to start and had to be nursed along. During this initial expansion our staff men were on the spot ready to advise and assist.

We established as our prime objective the application of Statistical Quality Control to at least one series of operations in every production department in the Company. In this way we would create a representative exposure. Practically, this seemed the best plan, and psychologically, it seemed the surest method of indoctrination. It brought to many jobs and to many people simultaneously the principles of Statistical Quality Control. This first objective is now an accomplishment. We now have nearly 3000 control charts in active use throughout our manufacturing and assembly divisions and 5000 applications in receiving inspection areas, and this number is being increased daily. Figures 2-6 show some of the chart applications at various Ford plants.

Earlier we mentioned the Quality Improvement exhibition which was held by Ford in November of last year. At that time the Quality Analysis Department was faced with the problem of illustrating the principles of Statistical Quality Control in an interesting and informative manner. After a great deal of thought we decided upon the following idea which is developed in Figures 7-11.

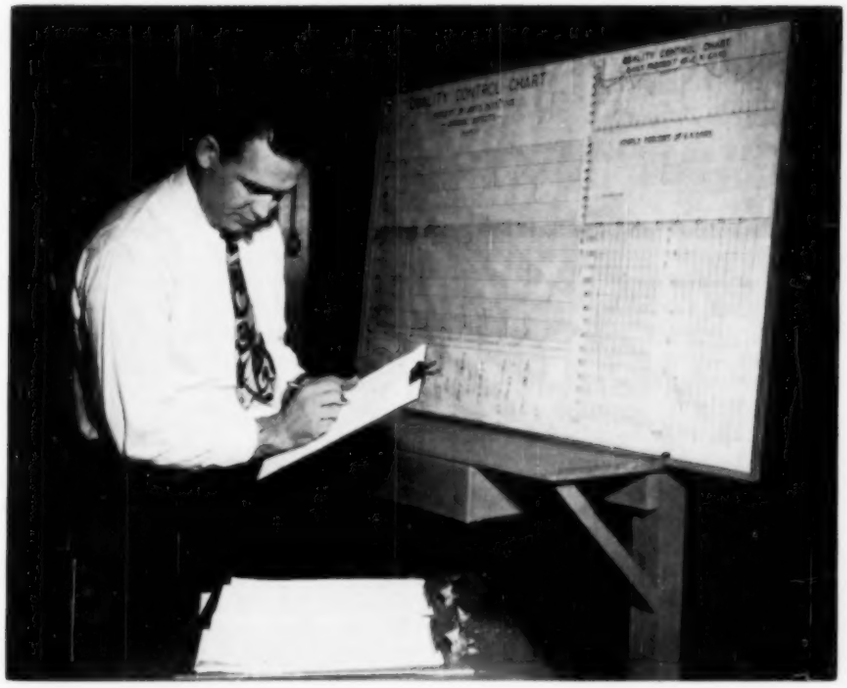


Figure 6—**Quality Control Chart Used on all Final Assembly Lines Throughout the Company.**

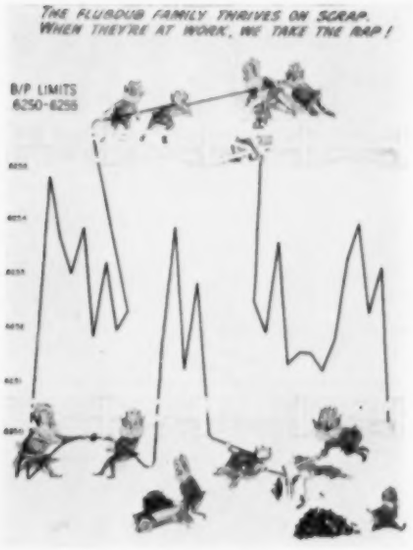


Figure 9

However, in this picture we see that the application of Statistical Quality Control has considerably reduced the points falling outside of the specification fences. Our exposure to the mischief of the "flub-dubs" is becoming less.

Figure 7

Need we mention that this is a scrap and rework pile—a condition which all of us are bent on avoiding!

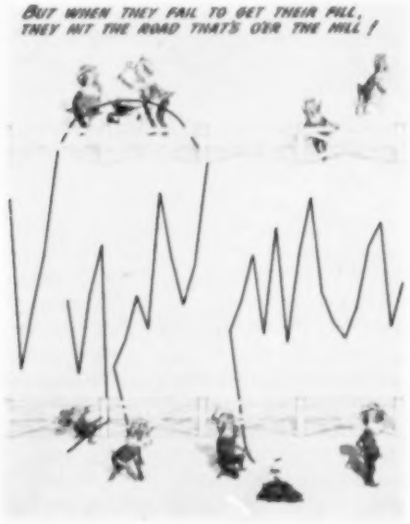


Figure 8

In this one we introduce you to the "flub-dubs" as we have christened them. The flub-dubs, on the other hand, are bent on piling up our scrap and rework losses. See how they make away with everything that falls outside of the fences.

Figure 10

Now we have the desired state of affairs—a job well in control, and the "flub-dubs" on their way to our competitors!

Figure 11

This last picture is what we are looking for—cash in the bank—the ultimate result of controlled operations. Quality products and job security for our employees.

This is the logical sequence of Statistical Quality Control. We see and recognize the fault; we analyze it; we apply corrective action; and we eliminate it.

COOPERATION WITH VENDORS

So far the remarks have been confined to the methods adopted to promote interest and apply Statistical Quality Control in our own plants. But if we are to attain the ultimate in quality we must be sure that all the production and service parts received from our vendors also meet our quality requirements. There are some 700 of these major production part vendors—some already using the statistical method of controlling product quality. The Quality Control organization at Ford, in conjunction with Purchasing and Training Departments, has recently completed the first part of a large-scale campaign designed to urge our suppliers to adopt the new statistical methods.

Here is a brief review of this program. The first step was the distribution of a formal kick-off letter introducing to all vendors the Ford Motor Statistical Quality Control program. In this letter we stated that our Training Department would be pleased to offer indoctrination courses in Statistical Quality Control to key men from our vendors' plants. In addition we asked our vendors if they would like to have a Ford representative visit them for a discussion of Statistical Quality Control. The results have indeed been gratifying. By March 31, when the first part of this program was completed, 258 men representing over 100 companies had visited our Training Department and received a day and a half instruction in Statistical Quality Control. At the same time they were conducted on tours of our plants where they were shown actual Statistical Quality Control applications. In addition to this our representatives have called on firms and given them the benefit of our experience in establishing their initial applications.

Without exception our vendors have shown a great deal of enthusiasm and have indicated that the training and personal contact visits have been very helpful to them. From our point of view the results have been so gratifying that we plan to repeat the program.

What will be the logical and final outcome of such a program? In a nutshell: *shipment quality certification*. The day when a supplier will say to us "I guarantee that this shipment meets the quality standards which you, the Ford Motor Company, and I, the supplier, have agreed upon. Enclosed form shows the basis on which I have certified."

What benefits will our suppliers gain? The benefits of Statistical Quality Control—the assurance that they are producing the highest quality at the most economical operating level.

LOOKING TO THE FUTURE

Our program so far has encompassed the training of our workers, a mass psychological approach, and the installation of statistical methods to actual operations. We are now in the throes of the expansion phase and it is our intention to apply Statistical Quality Control to every applicable operation.

If we do a little summing up we find that quality, economy, and worker morale are so closely interrelated that they might be compared to a three-legged stool. If one leg is missing, the whole program topples over. But if we have all three of those things—quality—economy—and worker morale—in high enough degree our competitive position in business is secure. The ultimate, and desirable result is, the highest quality product for our customers at an economically attractive price. It is our aim not only to maintain our position in industry but to enhance it. We must remember that it is the enterprising concern, bettering the old, and adopting the new and more efficient methods, which is going to lead the field, and have customer satisfaction as shown in Figure 12.

It is our intention to continue to improve the relationships with the men and women who are our employees so that they may have a better understanding of our policies and problems, and of our constant program of trying to provide the largest number of steady jobs for our people.

Figure 12

The job ahead of all of us is to build quality products for lower and lower cost. We realize that our continued success requires that we constantly advance in both quality and efficiency. Again, let us say that we recognize in Statistical Quality Control a tool which gives us the economical benefits of controlled operations, and which gives our customers the benefits of better products. Hence Ford's interest in Statistical Quality Control.

Watch for program details covering

SQC IN AUTOMOTIVE INDUSTRIES

Fifth ASQC National Convention
Cleveland, May 23-24, 1951.

A Chi-Square Chart for Controlling a Set of Percentages

ACHESON J. DUNCAN

The Johns Hopkins University

SOME years ago Dr. W. A. Shewhart suggested the use of a χ^2 test as a "fifth" criterion for detecting lack of control in a process.* The essence of his procedure was to compare the actual distribution of a sample of output with a theoretical or standard distribution. If the deviation of the actual from the standard distribution yielded a χ^2 for which the probability fell below .001, the process would be considered "out of control". Whereas Shewhart's Criterion I has developed into the present-day $\bar{X}$ and R charts, which are widely used, his Criterion V, so far as the writer knows, has had little usage. It is the purpose of this paper to describe how a χ^2 control chart, modeled after Shewhart's Criterion V, might serve as a useful control device.

APPLICATION OF χ^2 CONTROL CHART

The type of situation in which a χ^2 control chart might be of particular use is one in which the output of a given process is divided into more than two categories. The ordinary p chart was devised to control a product that may be classed as either defective or non-defective. Sometimes, however, product is divided into several categories. Often defective units are subclassified into those with major defects, minor defects, and incidental defects. Occasionally the classifications are more specific. Carbon resistors, for example, are graded as $\pm$ 1%, $\pm$ 2%, $\pm$ 5% and $\pm$ 10%. Cylindrical flint glass bottles are graded into six different degrees of temper.

It will be noted that the illustrations pertain to discrete items—"units", "resistors", "bottles". Since the χ^2 control chart is based upon the multinomial distribution, it must by necessity be restricted to discrete data. It cannot, for example, be applied logically to the control of percentages of fluid or chemical mixtures where discrete units cannot be distinguished. Whether it can be applied to physical mixtures depends on the ability to estimate readily and accurately the number of units involved. For example, granules of asphalt are graded as to size by passing them through sieves with different meshes. The portions retained by each sieve are weighed and expressed as a percentage of the total weight of the sample. If it is feasible to translate these weights into an equivalent granular count, a χ^2 control chart can be used.

*W. A. Shewhart—"Economic Control of Quality of Manufactured Product", pp. 328-340. D. Van Nostrand Company, Inc., New York, 1931.

A χ^2 CHART VS. A SET OF p CHARTS

When output is divided into several categories, control of the process may be undertaken in two ways. One is to set up individual p charts for each grade of output; for example, a chart for + 1% resistors, another for –1% resistors, a third for + 2% resistors, a fourth for –2% resistors, and so forth. These would form a set of charts that could be used to control the output of resistors. An alternate procedure is to set up a single χ^2 chart which would serve as a summary control chart for the process. It is shown in the Appendix that this second method is the statistical equivalent of the first. The selection of one or the other of the two methods will depend accordingly on its convenience and adaptability to a particular situation.

The individual p chart method has the advantage that it is similar to standard procedures and may for that reason be better understood. It has the disadvantage that it requires more charting. The charts will also have to be studied both individually and collectively, which may become cumbersome if there are four or more of them.

The principal advantage of the χ^2 chart is that it presents a single summary index of control. Management may prefer to glance at a single chart to get an over-all picture than to study a number of individual charts. If details are desired, they can be obtained directly from the tabled data upon which the χ^2 chart is based. A disadvantage of the χ^2 chart is that it is less well understood. It also does not take account of signs and therefore is not as fine an instrument for detecting changes. The arithmetic for maintaining a χ^2 chart is somewhat greater than required by a set of p charts, but the disadvantage on this score is not great, especially if the samples necessarily vary in size.

EXPLANATION OF A χ^2 CONTROL CHART

A χ^2 control chart is most easily explained by reference to a concrete example.

Suppose the output of a given process is classified as Grade A, B, C, or D. When the process is under control, it is found that the percentages of each grade turned out are as follows:

Grade A	12%
Grade B	54%
Grade C	25%
Grade D	9%

Management wishes to keep the process under control at these levels.

To maintain control, a sample of 100 units is taken at specified intervals and the number in each grade determined. The results of the inspection are listed in column II of a worksheet such as shown in Figure 1. The difference between the actual number in each grade and the average or expected number is taken, squared, and divided by the expected number (see Figure 1). The final figures for each grade are then added and plotted on a chart. (See Figure 2.) This chart will usually have only an upper control limit. For the problem in hand, this limit is set at 14.2. If the process is under control this limit has a probability of approximately .0027 of being ex-

ceeded by chance. A point beyond 14.2 will suggest that the process has changed with regard to the proportions of the different grades it is turning out.*

The control chart just described is called a χ^2 control chart because the plotted quantities have a chance distribution of the form of the χ^2 distribution.** The upper limit is the .0027 point of the χ^2 distribution for an n ("degrees of freedom") equal to one less than the number of grades into which the output is divided. In the above illustration $n = 4 - 1 = 3$, and 14.2 is the .0027 point of the χ^2 distribution for $n = 3$. The mean line on the χ^2 chart is at n. A table of the upper .0027 points of the χ^2 distribution follows.

The Upper .0027 Point of the χ^2 Distribution for Values of n from 2 to 25

n	χ^2
2	11.8
3	14.2
4	16.3
5	18.4
6	20.2
7	21.9
8	23.6
10	26.8
12	30.3
14	33.4
16	36.4
18	39.3
20	41.9
25	49.2

Read graphically from James F. Crow, "A Chart of the χ^2 and t Distributions", *Journal of the American Statistical Association*, vol. 40, p. 376. The maximum error is about .2.

A χ^2 CHART WHEN THE SAMPLE SIZE VARIES

In Figure 1, it was assumed that the number of cases was the same in each sample. This is not necessary. The samples may vary in size without requiring any change in the chart.[1] In each case the numbers placed in column I are 12% of the sample, 54%, 24%, and 10% respectively. In column II, are placed the number of items actually obtained from each grade. The only restriction[2] is that the sample should be large enough to make the number expected in any grade at least equal to 5.

Figure 3 illustrates a data sheet for a χ^2 control chart when the size of sample varies. Such a situation might arise, for example, if the "sample" was taken as the daily output of the given product. In this case there would be no direct control over the sample size and the standard percentages appearing in column I would not in most cases be simple integers. This complication necessarily increases the amount of calculation. If production does not vary considerably, however, it would be feasible to construct a table of the standard percentages for expected sample sizes. (Calculation to one decimal place should be sufficient.) The figures in column I could then be read directly from the table. The task of squaring column III can also be simplified by using tables of squares. Computation of column II requires merely subtraction, so that the only "involved" computation on

Figure 1—**Data Sheet for a χ^2 Control Chart, Constant Size Sample.**
(Size Sample 100. Number of Grades 4. Control Limit: 14.2.)

Sample No.	I Number Expected	II Number Obtained	III II—I	IV (III)^2	V IV ÷ I
Sample #1					
A	12	15	3	9	.75
B	54	46	−8	64	1.18
C	24	25	+1	1	.04
D	10	14	+4	16	1.60
					3.57*
Sample #2					
A	12	20	+8	64	5.33
B	54	52	−2	4	.07
C	24	20	−4	16	.67
D	10	8	−2	4	.40
					6.47*
Sample #3					
A	12	11	−1	1	.08
B	54	50	−4	16	.30
C	24	27	+3	9	.37
D	10	12	+2	4	.40
					1.15*
Sample #4					
A	12	24	+12	144	12.00
B	54	48	− 6	36	.67
C	24	25	+ 1	1	.04
D	10	3	− 7	49	4.90
					17.61*

*Plot these totals on the control chart. See Figure 2

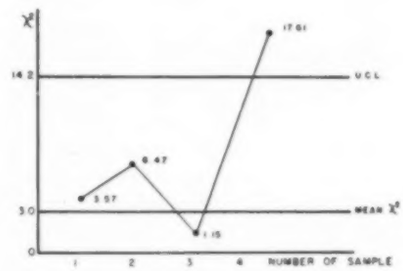


Figure 2—**A χ^2 Control Chart**

*For a normal distribution the probability of exceeding 3σ limits is .0027. Hence a .0027 limit for a $\chi 2$ chart is the equivalent of 3σ limits on an ordinary chart.

Since the deviations are squared and their sign is thus lost, there is no lower limit in a $\chi 2$ chart corresponding to the lower limit on a p chart.

A lower limit could be put on a $\chi 2$ control chart, but it would have a different significance. A point below such a limit would not indicate that the process was out of control, but merely that the "fit" to the standard proporions is "too good to be true". Such a point might suggest for example that the inspection records had been tampered with or that there was a mistake in the calculations.

**See any advanced book on statistics.

1. It is pointed out below, however, that a constant size sample permits interpretation of the results in terms of absolute goodness of fit to the standard percentages. If the samples vary in size, only relative goodness of fit can be considered.
2. This is the conventional rule. However, W. G. Cochran has shown that in tests of goodness of fit, such as here involved, the tabular χ^2 gives sufficiently good results for expected one-tail frequencies as low as 0.5. He writes, "The exact and tabular probabilities agree reasonably well down to a certain significance level, this being .0271 for m_3 (the expected frequency) = 1, (and) .0285 = for $m_3 = 0.5$. . . . Thereafter, the tabular χ^2 begins rather abruptly to underestimate seriously." See W. G. Cochran, "The χ^2 Correction for Continuity", *Iowa State College Journal of Science*, vol. XVI, (1942), p. 429.

Figure 3—**Data Sheet for a χ^2 Control Chart, Varying Sample Size**
(Number of Grades = 4. Upper Control Limit = 14.2)

Sample No.	I Number Expected	II Number Obtained	III II–I	IV (III)^2	V IV ÷ I
Sample #1 N = 112					
A	13.4	16	2.6	6.76	.50
B	60.5	58	–2.5	6.25	.10
C	26.9	27	.1	.01	.00
D	11.2	11	– .2	.04	.00
					.60
Sample #2 N = 90					
A	10.8	8	–2.8	7.84	.73
B	48.6	55	6.4	40.96	.84
C	21.6	23	1.4	1.96	.09
D	9.0	4	–5.0	25.00	2.78
					5.44

the data sheet is the determination of the quotient entered in column V. In most cases this can be done with a slide rule, yielding approximate results to three figures.

When the size of sample varies, the amount of work involved in the use of a χ^2 control chart is probably no more than would arise if a set of p charts were employed. If control limits on the p chart were based on an average sample size, some saving might be accomplished, but if control limits vary from sample to sample with the difference in sample size, or if a standardized p chart* is employed, varying sample sizes will increase the amount of work involved as much as they do in the case of a χ^2 chart.

SETTING UP A χ^2 CHART

The procedure for setting up a χ^2 chart is similar to that of setting up a p chart. Suppose that the standard percentages for each category are not given by some *a priori* formula but are to be determined from the process when it is under control. To establish control and to find the process average percentages, suppose that 20 samples of 100 each are taken from the process. From the grand sample of 2000, preliminary estimates can be made of the percentages falling in each category. These percentages become the preliminary standard. From them an initial χ^2 control chart can be set up showing the 20 values of χ^2 for the 20 samples. If one or more samples have a χ^2 outside the control limit, assignable causes should be looked for. Investigation should also be made of "lack of control" indicated by runs above or below the average or runs up or down. All samples whose peculiar variation can be attributed to assignable causes should be thrown out and a new standard of percentages computed for the χ^2 chart. This standard will then become the initial standard to be used, say, for the first month's operation. Subsequently, it may be revised if the data indicate the desirability of a change. It is to be noted that for the most part a χ^2 chart may be interpreted like any other control chart. As usual, points above the control limit would indicate lack of control. A run up would indicate that the process is moving away from the prescribed percentages, and if it continues long enough, say for seven or more samples, action should be taken. Likewise a long run above the mean would indicate a shift in the process percentages.

INTERPRETING A χ^2 CHART

The principal difference in interpretation between a single p chart and a χ^2 chart is in respect to runs below average or runs down. On a single p chart a run below average or a run down indicates a shift or a trend to a higher quality, or possibly a deterioration in the effectiveness of inspection. On a χ^2 chart, a run below average or a run down indicates a closer agreement with the standard set of percentages. On a single p chart, shifts to lower levels might possibly be maintained if the reasons for the improvement in quality are discovered and these more favorable conditions are maintained. Shifts to below-average levels on a χ^2 chart cannot be maintained under random conditions. For a shift to a low level of χ^2 indicates that the fit is getting "too good to be true". It suggests that the sampling procedure is no longer random or that inspection records are being tampered with, or that there is an error in the calculations.

Another point that needs to be made clear is that χ^2 is independent of the size of the sample employed. It is true, of course, that a larger sample will, on the average, give a better fit to a standard set of percentages than a smaller sample. The χ^2 chart, however, takes this into account, and the closeness of fit which it measures is the closeness expected for the given size sample. The χ^2 chart is similar in this respect to a standardized p chart which expresses deviations from the average in standard deviation units.** It is for this reason that a χ^2 chart is equally valid for constant or varying size samples. The average and control limit on a χ^2 chart are determined solely by the number of categories for which percentages are figured. If it is desired that the various values of χ^2 have the same significance in terms of *absolute* goodness of fit, then it is necessary to take all samples of the same size.

If the χ^2 chart indicates a significant shift from the prescribed standard, the χ^2 table from which it is computed will indicate just how the shift is being effected, because this table gives the individual components that make up the total χ^2. If a large χ^2 is made up of large contributions by each component, it would signify an overall shift away from the standard percentages. On the other hand, if a large χ^2 is the result of a large contribution by a single component, it would indicate that the process was getting out of line primarily with respect to one particular percentage. Finally, if a large χ^2 results from large contributions by two components, it would suggest that the process is tending to increase the percentage of one component at the expense of the other. A study of the χ^2 table will thus facilitate the finding of the causes of the shift.

* A p chart in which the variation in p is measured in standard deviation units. See A. J. Duncan, "Detection of Non-Random Variation When Size of Sample Varies", this journal, Jan. 1948, pp. 9-12.

** Cf. A. J. Duncan, Ibid.

CONCLUSION

In conclusion, it should be pointed out again that the χ^2 chart measures only the *amount* of departure from the given standard. It takes no account of signs. It would be possible, for example, for categories A and B to show small positive deviations and categories C and D to show small negative deviations without the χ^2 for the whole sample being exceptionally large. If the categories A, B, C, and D formed a continuum, this increase at the upper end and decrease at the lower end might well indicate a tendency for the process to shift toward higher values. Such a shift would not be caught by the χ^2 chart until it was significant in an absolute amount. For this reason it is well to study the signs of the deviations in column III of the χ^2 table to note small shifts in direction that the χ^2 chart itself may fail to catch immediately. Such a "sign test" will be more useful the larger the number of categories of classification.

APPENDIX

That a χ^2 chart is the equivalent of a set of p charts may be shown as follows.

Let the output be graded as A, B, and C, and let the fraction of A in any sample, the fraction of B, and the fraction of C be taken as the coordinates of a point in space. Then all such sample points will be in a plane such as plane XYZ of Figure 4, for we must always have
(% A) + (% B) + (% C) = 100%,
which is the equation for a plane. If we lay the plane XYZ out flat, it will look like Figure 5, which is the easiest way to show the relationship between a set of three p charts and a χ^2 chart.

If the process is such that it is actually turning out (⅓)A, (⅓)B, and (⅓)C, and if the sample contains 120 items, the central lines on each of the p charts that would be set to control the three grades will be .333 and the 3σ limits will be .204 and .462. These 3σ limits are marked off in Figure 4 and shown more clearly in Figure 5. For a sample result to be within control limits on all three p charts, it must fall within the hexagon *abcdef*. The point P, for example, meets this requirement. The point P′ is within the 3σ limits for grade A but not for grades B and C. Figure 5 may thus be viewed as a joint control chart for the three individual fractions.

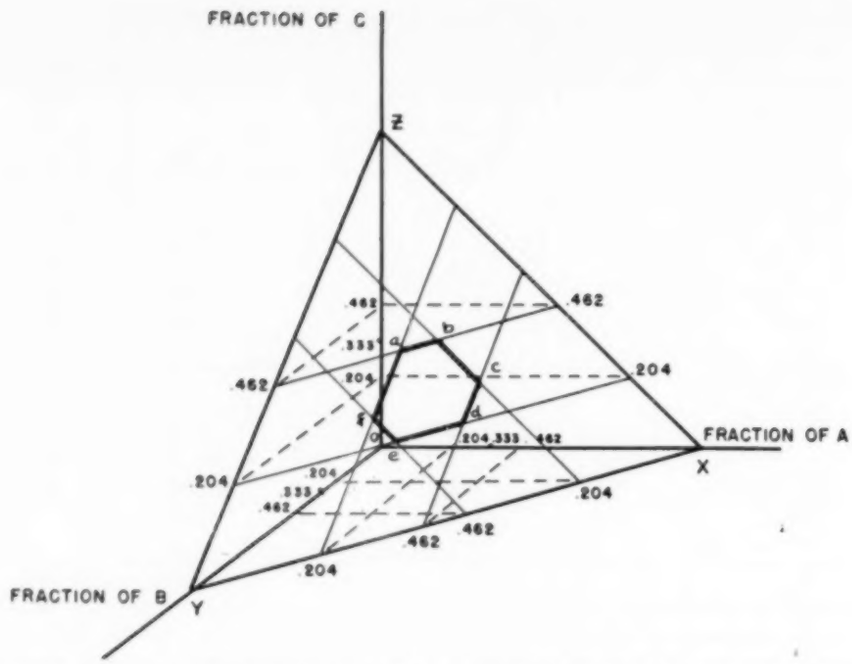


Figure 4—**The Joint Distribution of the Sample Fractions in Each of Three Grades ($p_1 = p_2 = p_3 = ⅓$, N = 120) with 3σ Limits for Each Sample Fraction.**

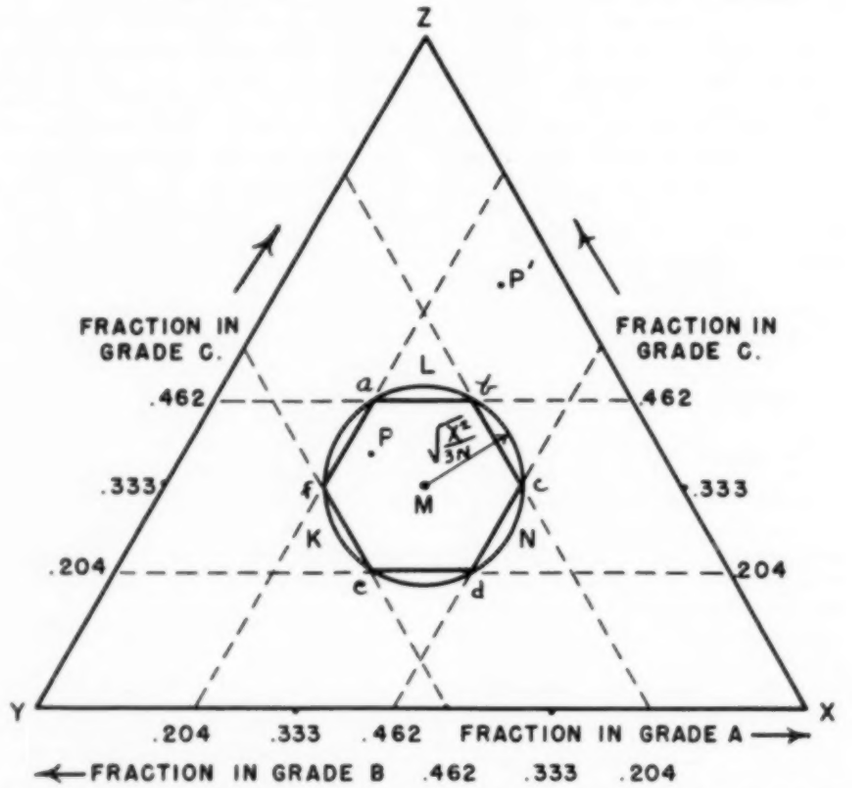


Figure 5—**The XYZ Plane of Figure 4 Laid Out Flat, Showing the 3σ Limits for the Fraction in Each Grade (assuming $p_1 = p_2 = p_3 = ⅓$, N = 120) and the χ^2 Limit at .0027.**

The point M at the center of the triangle XYZ has the coordinates p_1, p_2, p_3, or in our particular example ⅓, ⅓, ⅓. The coordinates of any sample point are
N_1/N, N_2/N, and N_3/N.

The square of the distance of a sample point from the central point M is thus

$$(N_1/N - 1/3)^2 + (N_2/N - 1/3)^2 + (N_3/N - 1/3)^2 = \Sigma(N_i/N - 1/3)^2 = \Sigma(N_i - N/3)^2/N^2 = D^2.$$

But in this case, we have by definition,

$$\chi^2 = \frac{\Sigma(N_i - N/3)^2}{N/3}.$$

Therefore $\chi^2 = D^2(3N)$, or the distance D equals $\sqrt{\chi^2/3N}$. Hence the upper limit on the χ^2 control chart that could be used to control a set of three grades will be represented in Figure 5 by a circle, all of whose points lie at the distance $\sqrt{\chi^2/3N}$ from the central point M. The circle KLN of Figure 5 is the circle for which $\chi^2 = 11.8$, which is the .0027 point for a χ^2 distribution with $n = 2$. Every sample point which lies within this circle will be "in control" on the χ^2 control chart. It will be seen that the samples included within the χ^2 limit and those included within the 3σ hexagon are practically the same set of samples.* In other words, the use of 3σ limits on three individual p charts gives essentially the same control as that of a χ^2 chart with a .0027 limit.

The above analysis is based on the assumption that the true fractions in each grade are all 1/3. A similar analysis will show that these two systems are approximately equivalent even when the fractions are all different. The approximation is not as good as in the instance discussed above, but it is still good enough for practical purposes.

* It must be remembered that the samples occur only at discrete intervals in the plane XYZ so that the difference between the area of the circle and the area of the histogram is not as important as it might first appear.

On the Evaluation of Raw Stock Dyeing

A. G. KLOCK
Quality Control Superintendent

C. W. CARTER
Quality Control Engineer

Bigelow-Sanford Carpet Company, Inc.

IN APPLYING the techniques of quality control to an industry in which quantitative measurements are easily obtainable, the procedure has been well developed and is relatively straight forward. However, in an industry such as textiles, it is not always possible to obtain quantitative measurements. Thus, there is a problem of determining quality levels. Quality levels are dependent upon the approximate measurement of performance through the medium of opinions. This procedure must have a sound basis in order to yield valid results.

As an illustration, consider the problem of evaluating the raw stock dyeing of textile fibers. How may we get a reliable weekly index of the quality level? Can we safely say that this weekly dyeing shows an improvement over that of last week? When are we headed for trouble? In order to answer these questions the Quality Control Department of the Bigelow-Sanford Carpet Company developed a technique for polling and analyzing opinions concerning the quality of dyeing.

Before considering this technique, it would be well to discuss the major problems encountered in raw stock dyeing. The critical problem is matching a pre-determined color standard; not with just one kettle, but with a succession of kettles so that the final blend of fibers will be a *commercial match*.

When a batch has reached its specified size and its color does not match the standard, the dyer must dye additional amounts of fiber to such color that the composite blend will be of a satisfactory color. This quantity expressed as a percentage of the batch weight is known as the *percent of overrun*.

BIGELOW-SANFORD CARPET COMPANY
THOMPSONVILLE, CONNECTICUT
QUALITY CONTROL DEPARTMENT

RAW STOCK DYEING

OPINION POLL RATING SHEET

NAME _____ WEEK ENDING _____

CLASS	BATCH NUMBER
1. EXCELLENT	
2. VERY GOOD	
3. GOOD	
4. FAIR	
5. SATISFACTORY	
6. QUESTIONABLE	
7. UNSATISFACTORY	
8. POOR	
9. WILD	
10. EXTREMELY WILD	

Figure 1

The effect of an unusually large percent of overruns is serious: time is lost, deliveries are delayed, and imperfect fabric may be increased due to the non-uniformity of the batch of fibers.

During a period of high percent of overruns, the Quality Control Department had developed a technique for evaluating the quality of raw stock dyeing. This consisted of a weekly review, by the Quality Control Staff, of carded swatches from each kettle in a batch. The opinion poll rating sheet shown in Figure 1 was used by each of five staff men to rate each dye batch dyed during the preceding week. The rating was given according to the numbered classes varying from class 1 (excellent), to class 10 (extremely wild). The term, "wild," as applied to raw stock dyeing, denotes complete lack of control and is evidenced by swatches of many colors within the same batch. For example, green might be so far from standard that the necessary correction might be a dark brown.

Results of the weekly rating sheets are summarized first as a conventional control chart for sample size 5 and second, graphically as a fre-

quency distribution. The numbers associated with the adjectival ratings make it possible to obtain a numerical value for each batch and for each week's performance. In addition, a control chart based on the numerical values provides a measure of the consistency of the judgments of individuals by giving an average range. *Consistency* in this sense means only (a) that the adjectival opinions of the individual staff members vary linearly as indicated on Figure 1, and (b) that the sensings of the person do not vary greatly from time to time. The average range for a typical period does not show sensing on the scale to be out of control. Table 1 and Figure 2 present the evidence.

TABLE I—Dye House Opinion Poll Weekly $\bar{R}$ for March-May, 1949

Week	No. of Batches	$\bar{R}$	$n\bar{R}$
1	12	2.0	24.0
2	12	1.4	16.8
3	10	1.3	13.0
4	12	1.6	19.2
5	11	1.4	15.4
6	11	1.5	16.5
7	11	1.7	18.7
8	9	1.6	14.4
9	8	1.3	10.4
10	7	1.4	9.8
11	8	1.7	13.6
12	10	1.6	16.0
13	7	1.4	9.8
Totals:	128		197.6
Ave.:	$\bar{n} = 9.8$		$\bar{R} = 1.54$

Control limits for $\bar{R}$'s based on average batch size $\bar{n} = 9.8$:

$$UCL = 1.36\bar{R} = 2.09$$

$$LCL = 0.64\bar{R} = 0.99$$

$$1.36 = 1 + (D_4 - 1)/\sqrt{n}$$

$$0.64 = 1 - (D_4 - 1)/\sqrt{n}$$

$$D_4 = 2.114$$

Note: These control limits should be regarded as first approximations to their theoretically correct values, since an exact formula for σ_R is not available.

The frequency distribution provides a visual composite evaluation representative of each week's performance. In this way different shifts or trends can be detected which might not be noticed from the average alone.

At the outset of this program, it was clear that the validity of this approach had to be demonstrated.

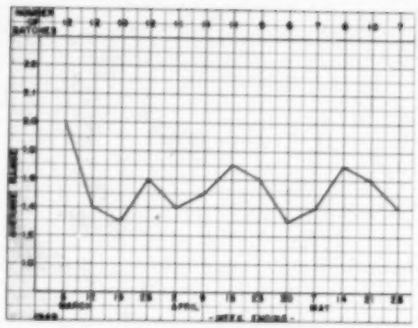


Figure 2—**Dye House Opinion Poll —Weekly Average Range for March-May, 1949**

By reviewing two weeks' production, setting it aside for a month, and reviewing it a second time, we were able to check the repeatability or consistency of the judges, though not necessarily their correctness. Figure 3 shows the distribution of the original and the subsequent evaluations of the same batches. Whereas there are some discrepancies, nevertheless the repeatability was generally good.

At the beginning of 1949, the Quality Control Department embarked on an extensive engineering study of the raw stock dyeing process. This study lasted approximately six weeks, during which time controls were established for dyeing formulae, pH, blends, and a number of other variables. Toward the end of February, a definite improvement had been noticed in the opinion poll index; and by May its level had improved from somewhere between 5 and 6 to a level in the vicinity of 3. This trend is shown in Figure 4. Concomitantly, the percent of overruns was steadily decreasing. This trend is shown in Figure 5, where a

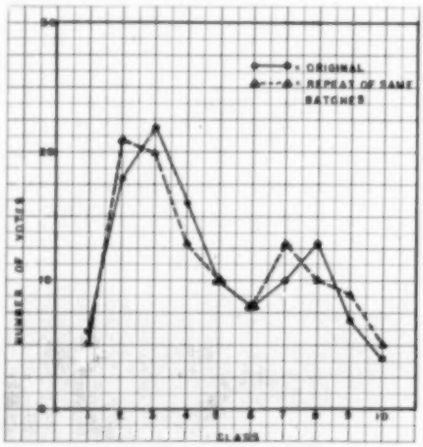


Figure 3—**Raw Stock Dyeing Opinion Poll—Test for Repeatability**

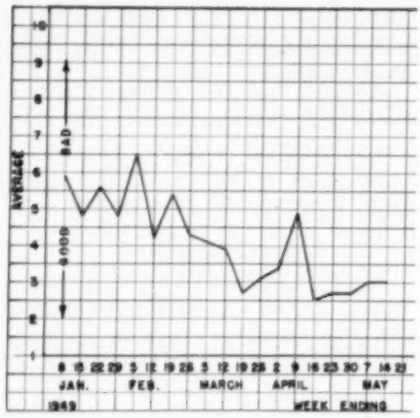


Figure 4—**Dye House Progress Chart—Opinion Poll Index**

decrease of about 7% is apparent. There appears to be a correlation between the opinion poll index and the percent of overruns. This would tend to substantiate the theory that close control of the dyeing process increased the dyers' ability to match a standard at the scheduled batch size.

The elimination of assignable causes of variation in the dyeing process and keeping control charts on some of the chance variables helped the dyer do his job.

Finally, a method has been developed for measuring quality levels in the Dye House which can disclose improvements or declines in quality from week to week and can warn one of impending trouble.

Thus it appears that the techniques of quality control can be applied in a useful manner to an operation in which qualitative opinions are the sole means of sensing quality characteristics.

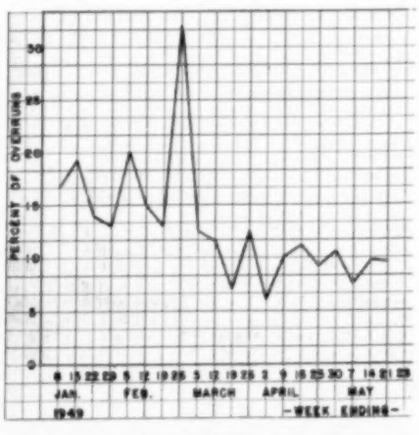


Figure 5—**Dye House Progress Chart—Overruns**

Quality Control in the Production of Blended Whiskey*

DAVID R. PERYAM

The Calvert Distilling Company, Baltimore, Maryland

WHY do people use liquor? There are many correct answers to this question, for drinking is a complicated bit of behavior, but to the manufacturer in his quest for a quality product, one answer must be paramount. Quality liquor is not necessary to satisfy those who drink only for the gross effect; all that is needed is percentage of alcohol. For most people, however, the immediate sensory pleasures of taste and smell constitute a very important part of the total satisfaction of drinking, and this creates a consumer demand for quality which the manufacturer must meet if he will survive. Recognition of this condition is the guiding philosophy of The Calvert Distilling Company's whole quality program, which includes research and development as well as the product acceptance method which will be discussed here.

That we have a product whose essence is a thing as intangible as human pleasure brings about problems of measurement quite different from those encountered in the usual quality control situation. The human senses will ultimately judge our product, and we have found that these same senses constitute not only the best measuring device for quality, but actually the only workable one. It is a natural tendency to want to apply to this problem what are termed the more exact methods of control, i.e., chemical and physical tests, but attempts to use such methods have been, uniformly, failures. Surely one must assume that every sensible flavor variation has a corollary chemical variation even though the latter may be difficult or impossible to verify. However, the human senses of smell and taste are among the most delicate chemical measuring devices known. When dealing with substances that cause taste and odor sensations they can detect much finer variations than even the most precise chemical techniques and can do so with a great deal less labor. It can be stated as a general principle, not confined to the alcoholic beverages, that chemical tests are by comparison but gross predictors of flavor.

*Presented before the Baltimore Section, ASQC, November 15, 1948. Mr. Peryam is at present Chief, Acceptance Division, QM Food and Container Institute for the Armed Forces, Chicago, Ill.

GENERAL BACKGROUND

At each of our Company's operating plants we have established an organization which we designate as The Quality Laboratory. They are essentially psychology laboratories rather than whiskey laboratories; their basic procedures are determined by that science and their function is to use human observers in development and process control work and, finally, to handle the important task of product acceptance. It is the test used for the latter purpose which will be described here.

The traditional method of quality control in the liquor industry is the expert system in which one or a small group of expert tasters attempt to handle the job by virtue of particularized knowledge of whiskey and by individual sensory skill. The experts must presume both unerring judgment and unerring sensory perception. Our laboratory methods, in contrast, put taste-testing on a scientific level and both validity and reliability of results are markedly enhanced thereby.

Control testing implies a standard. The subjective standard used by the consumer, and by the expert taster, consisting as it does simply of a knowledge of what is good, is too vague, too subject to chance variation, to be an accurate guide. Our solution is to create a physical standard which embodies the flavor we wish to maintain. Then we test in terms of difference from this standard. Capricious change is thereby avoided and we also take advantage of the fact that such difference testing can be much more precise than the testing of absolute values. Originally, to obtain the standard for a given product, the best combination of ingredients that is possible, considering time and whiskey stocks available, is worked out by a series of taste preference tests using observer groups representative of the customer public. This standard is maintained by an extension of the same procedure used for acceptance work and any variation therefrom is made by prior decision.

In the production process the whiskey is blended in lots of from 8 to 10 thousand gallons according to a specific formula, worked out by the Quality Laboratory, which expresses the master standard in terms of the particular whiskeys available. After processing is completed a sample of each tank lot is submitted to the Laboratory for an answer to the question, "Can this lot be distinguished from its standard by sensory test?" If the answer is negative, the lot is accepted; if the answer is affirmative, the lot is rejected and must be reworked. When a rejection occurs it indicates either that one or more of the whiskeys or other raw materials used were non-standard or else that there has been an irregularity in the production process. In either case, the causes can be sought and, if identified, can be eliminated.

This system provides for a complete inspection of outgoing product at the completion of the blending process, since no lot of whiskey is sent to the bottling tanks until sampled and approved. The possibility of flavor contamination during the bottling operation is but slight. However, the Laboratory also makes periodic checks of samples taken from the bottling line.

TASTE-TEST PROCEDURES AND CONTROLS

With this general background established we will go on to specific

description of the test used, including some discussion of controls which are necessary.

Without doubt, the observers, i.e., the persons who do the tasting and judging, are the most important aspect of the Laboratory. Without these individuals, without their sensory and perceptual abilities manifested under conditions of proper control, the system is useless. Their selection and training cannot be haphazard and their performance must be continuously subject to review. Ten observers comprise the normal testing group. They are usually women, originally hired to work on the bottling lines, who have been assigned to the Laboratory on a trial basis and have proven their ability. Very likely an observer's sense of taste will be more acute than average, but the selection is made upon the basis of demonstrated ability to detect differences between whiskies. It should be emphasized that these people are not considered "whiskey experts" since their usefulness does not depend upon any kind of unusual knowledge or skill. Not only do they know what they are doing, but we know also, and a method is readily available for training replacements.

At present a taste test only is used in acceptance work. At various times an odor test has been used in parallel. However, the two correlated highly and, since the odor results were more variable, the latter test was dropped in the interests of inspection economy.

Basically, the test is quite simple. The observers taste 4 cc samples of whiskey from ordinary shot glasses. These samples are presented in a controlled order and the observer is required to make certain statements about them. Special apparatus has been designed to make administration of the test speedy yet accurate and the observers have been trained to follow procedures in testing which have proven to give best results.

Figure 1 diagrams the procedure of a single test. It shows the series of seven taste samples which is given to an observer at a sitting.

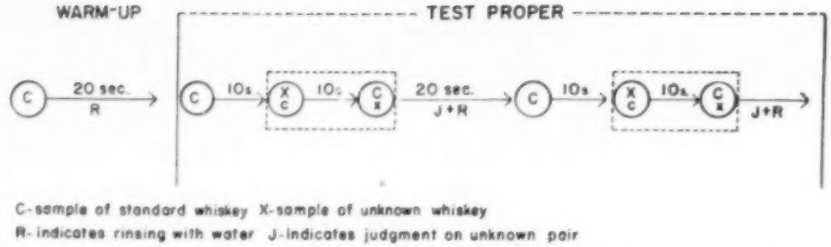


Figure 1—**Diagram of the Sample Series which Constitutes the "Test" Taken by an Observer at One Sitting.**

Prior to the start of the test proper the observer gets as a "warm-up" sample, 4 cc's of whiskey C which is the standard. The warm-up has this function: The first sample which is tasted may seem quite different from the others merely because of its temporal position and because of contrast with the previous neutral condition in the mouth. The warm-up readies the mouth, making conditions more nearly constant for the rest of the samples. It is followed by a minimum interval of 20 seconds during which the observer rinses with distilled water which is always available in quantity in the testing booth. In the test proper C is given first, followed, at 10-second intervals, by the two members of an X-C pair given in an unknown order. Next, there is another 20-second interval during which the observer gives his judgment and again rinses. Then the process is repeated, i.e., another C followed by a second unknown pair for judgment. The time required for the entire test is about two minutes. Test series for a given observer are separated by a minimum interval of 15 minutes to give the sensory mechanisms time for complete recovery.

The crux of the whole matter is the response. In this test the observer is fully aware of the entire series, i.e., he knows that the first sample is a "warm-up" and that in the test proper the first sample of a trio is always C and is followed by a pair in unknown order. He knows that, within the pair, one member will be identical with C but that the other *may* differ from it. He must state which of the two is the "different" sample. "But," you may object, "suppose he thinks they are identical and are both like the standard?" This does arise frequently, for X will be very close to C if the lot from which it was drawn has been properly blended. However, the test does not permit a "same" judgment; the observer must give his best guess. When we turn to analysis of the data we will see why this is necessary. It can be shown that this forcing of a decision is not unrealistic. Rather, it makes for finer discriminations. Not infrequently the test as a whole proves that a difference exists even though no single observer has been certain of his judgment.

The data are recorded simply as correct or incorrect for each judgment according to whether the observer has properly identified the X or not. The complete control test on a given production lot consists of ten of these individual test series using ten different observers. As each person gives two judgments there are 20 items for final analysis. When results with the 20 judgment test are doubtful, it may be extended to 30 judgments by having five observers repeat.

Controls which are vital if the test is to be effective fall into two general classifications. First there are those relating to the test samples, C and X, themselves. They must be identical in every aspect under laboratory control to assure that the observers will not get irrelevant cues.

1. Temperature must be equal. We have found that normal room temperature is optimum for difference testing.
2. Alcohol concentration (proof) must be identical since a difference of about 2% of proof is detectable by a trained observer.
3. There must be no variation in color.
4. All samples must contain the same volume.

The second class of controls is larger. Their need is dictated by common sense, refined by the science of psychology, to assure that the observer may work under optimum conditions. Most of them relate to the factors of adaptation and fatigue.

1. Use of the "warm-up" is a member of this class. It tends to make adaptation uniform.
2. The water rinses are employed to slow down the rate of adap-

tation to the flavor of whiskey, because, as it proceeds, finer differences disappear.

3. Also to retard adaptation, there is a "no-swallowing" rule. The entire sample is expectorated. When the whiskey reaches the deeper regions of the buccal cavity and the throat it can be perceived more fully. However, in that case rinsing is relatively ineffective and the net result is reduced sensitivity.
4. The samples are reduced to 45° proof, which is half the usual whiskey strength. At full strength, whiskey has such a strong flavor and tactual quality as to interfere markedly with taste perception.
5. Time intervals between samples must be controlled with two conflicting objectives in mind. At least a minimum of recovery time must be allowed but intervals cannot be extended to the point where forgetting becomes important.
6. The order of presentation within the unknown pairs is determined by chance. If it is the same all the time or follows any set pattern, constant errors might arise.
7. The testing situation must be kept free from distractions, both sensory and ideational, to permit observers to operate at the optimum. For example, smoking is not permitted in the laboratory. Production personnel are not allowed to discuss results with the observers.
8. Motivation is important. To make the system work the observer must consider each unknown pair a challenge. It is made explicit that the criterion of job success is the ability to make a good percentage of "right" responses. At the end of each test the observer is told the results and a continuous record is kept of each observer's percentage correct. He knows that the penalty for falling significantly below the performance level of the group is banishment from the attractive laboratory job to the comparative Siberia of the bottling lines. Also, a day by day competitive spirit is fostered among the observers.

For all the space necessary to describe it, the test and the attendant controls seem quite simple. Under controlled conditions we ask a question which can be answered, and the answer to which is unambiguous. Complete data on a single production lot will be either 20 judgments, or, in an extended test, 30 judgments. Judgments have been recorded as "correct" or "incorrect."

ANALYSIS OF TEST DATA

How do we use these data for control? Remember that all of these judgments may be guesses or, on the other hand, they may represent a greater or lesser degree of certainty on the observers' part. However, all are treated as being of equal value. Also each judgment is treated as a datum even though it is a member of a pair and there is probably some degree of correlation.

If blending of the lot under consideration has been normal the X will be identical in taste with the standard C, or quite close to it, and most of the judgments will be, actually, guesses. However, over a period of time lots will appear which cover quite a range of flavor variation. As difference from the standard increases, guessing will become less frequent and therefore the percentage of correct responses will be higher. How high must this percentage go before we can be certain that, considering the group of responses as a whole, they no longer could represent guess work? How high before we can safely say, "Here is a true difference?"

To answer this question we look at a hypothetical set of data. What can we expect to happen when the samples are identical? Here we have a situation analogous to the penny-tossing experiment where we record the percentage of heads in twenty tosses, for there are but two alternatives, and each observer has a 50-50 chance of being right on each judgment. Following this analogy further, we know that if we run our taste test on an identical X-C pair and then repeat the test many times over, recording the percentage of correct responses obtained each time, these percentages-correct will tend to distribute on the normal curve with 50% correct as the mean. (It has been established by experiment that the results on identical samples will so distribute.) Now we inquire as to the frequency with which any given percent-correct will occur.

We analyze our theoretical distribution in terms of the Standard Error, using the formula

$$\sigma_p = \sqrt{pq/N}$$

where

σ_p = Standard Error of a percentage;
p = percent correct;
q = (1-p), or percent incorrect;
N = number of cases.

Here the true mean is 50%. Therefore, $p = .50$, $q = .50$, $N = 20$,
$\sigma_p = \sqrt{(.5)(.5)/20} = .112$ or 11.2%.

The significance of the σ_p is that upon repetition of the experiment, the result will fall within certain σ_p limits from the mean percentage with a known frequency which can be determined by reference to a standard table of areas under the normal curve. Figure 2 diagrams the situation under discussion.

50% is the mean percent correct. Referring to the tables, 68.2% of all tests will fall within $1\sigma_p$ each way from 50%, i.e. between 61.2% and 38.8% correct judgments, and 95.4% will fall within $2\sigma_p$, or between 72.4% and 27.6% correct judgments. The expectancy that the result of the test will fall beyond any given σ_p point is represented by the area under the curve beyond this point. For example, we could expect 2.3% of all tests to fall beyond 72.4% correct judgments and the same percent to fall beyond 27.6% at the lower end of the curve.

Table 1 shows these calculations for all possible percentages using twenty judgments, and, for the thirty judgment test, the figures near the region which is critical for purposes of this test. Only half of the symmetrical curve is tabulated. In these calculations we have assumed a normal curve for the data. Since we are dealing with a binomial expansion this assumption is not strictly correct, but it is a close enough approximation for this particular application. Columns 1, 2, and 3 show, respectively, total judgments, number correct, and percent correct. Column 4 translates this percent correct into the σ_p distance from 50%. Column 5 shows the percent of area under the curve between 50% and this point, and Column 6, the percent beyond. Column 6 has another meaning since it also gives the chances in one-hundred of equalling or exceeding the given percentage correct.

To test for difference we compare any given result on an unknown lot

with this theoretical distribution and find out how often that result might arise with identical samples. If the latter frequency is low we conclude that there is a true difference. The reader may be interested in the significance of percentage-correct results below 50%. They usually represent nothing more than chance expectancy with identical samples. However, if any percentage is lower than chance reasonably would allow, we must conclude that the test was faulty—either that the observers were making some type of constant error or else that for some reason they were trying to defeat the test in order to approve the sample. In either case the test is repeated and with additional precautions.

With this analysis behind us we still have the problem of selecting a workable rejection point, one which gives assurance of customer satisfaction, yet one which can be met by production without too great expense. The breaking point at present in use is $2.2\sigma_p$, which point is indicated in Figure 2. Any test whose result falls below this point approves the lot; at or beyond, rejects it. Referring to Table 1, we see that at this point there are only 1.4 chances in 100 that the lot could be identical with the standard. Note, however, that this does not explicitly tell anything about the degree of difference between the two. It is a logical inference that greater σ_p ratings show larger degrees of difference, but the method does not require this to be true. In effect we have said only that it is highly improbable that the lot is identical with the standard; definitely we have not said that the difference is such that we should always expect such a result. In fact, a repetition of the test is quite likely to result in a lower percentage, although never as low as 50%.

ILLUSTRATIVE EXAMPLES

Following are examples of the system in operation. They can be checked by reference to Table 1.

Example 1

Number of judgments	20.
Numbered correct	13
σ_p rating	1.3
Disposition	The lot is approved.

Example 2

Number of judgments	20.
Number correct	16
σ_p rating	2.7
Disposition	The lot is rejected and must be reblended.

Example 3

Let us say that the 20-judgment test showed 70% correct. The σ_p rating would be 1.8. This is considered doubtful and the test is continued.

New total	30
Number correct	19
σ_p rating	1.5
Disposition	Approved

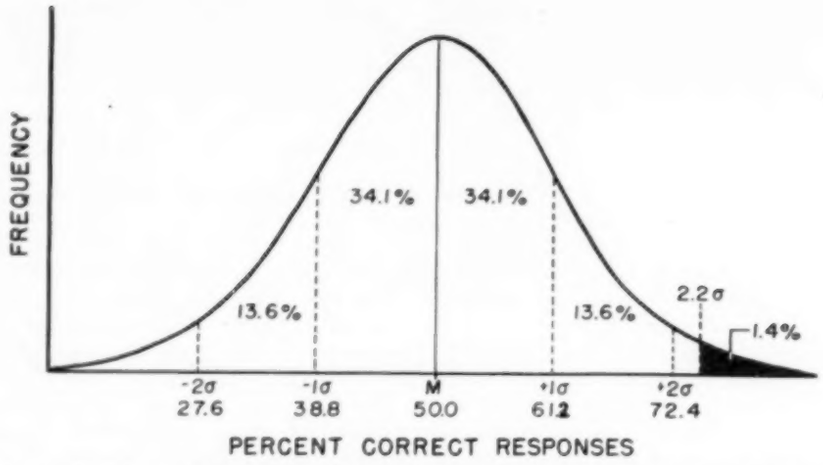


Figure 2—**Theoretical Distribution of Percentages Correct Upon Repetition of the Taste-Difference Test on Identical Samples Using 20 Judgments. Shaded Area Represents Production Risk with the 2.2σ Rejection Point.**

Example 4

The 20-judgment test shows 75% correct—σ_p rating, 2.2. Again this is border-line and the test is extended.

New Total	30
Number correct	21
σ_p rating	2.2
Disposition	Rejected and reblended.

CONCLUSION

Now let us consider, briefly, a few points which will be of interest to the theorist and the practical man alike.

This method does not attempt to

TABLE 1

Sigma-p Ratings and Areas Under the Normal Curve Corresponding To Given Percentages Correct

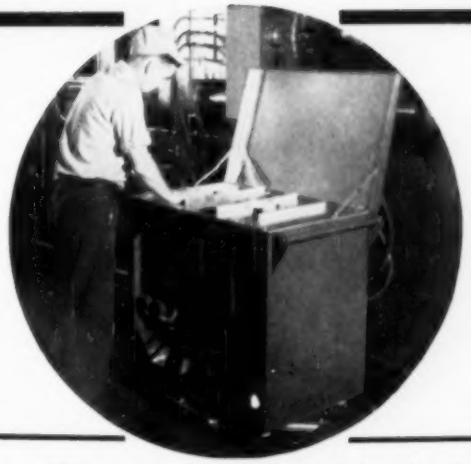
Total Judgments	Number Correct	Percent Correct	SE Distance from 50% (σ_p rating)	Percent area between 50% and this point	Percent area beyond this point
20	10	50.0	0.0	0.00	50.0
20	11	55.0	0.4	15.6	34.4
20	12	60.0	0.9	31.6	18.4
20	13	65.0	1.3	40.3	9.7
20	14	70.0	1.8	46.4	3.6
20	15	75.0	2.2	48.6	1.4
20	16	80.0	2.7	49.7	0.5
20	17	85.0	3.1	49.9	0.1
20	18	90.0	3.6	50.0-	Very small
20	19	95.0	4.0	50.0-	Very small
20	20	100.0	4.5	50.0-	Very small
30	18	60.0	1.1	36.4	13.6
30	19	63.3	1.5	43.3	6.7
30	20	66.7	1.8	46.4	3.6
30	21	70.0	2.2	48.6	1.4
30	22	73.3	2.6	49.6	0.4
30	23	76.7	2.9	49.8	0.2
30	24	80.0	3.3	50.0-	Very small

"prove" that the production lots are the same as the standard. Rather, it implies identity, for practical purposes, through failure to prove that a difference exists. This is the customer's assurance of quality. With an approved rating of 1.8 σ_p, it is still quite possible that there is a true difference, but since, even under optimum laboratory conditions, we cannot prove the fact, we know that under field conditions of liquor consumption, the difference will be unnoticeable.

Replenishment of standards represents a more difficult problem than the testing of production lots because here the accumulation of even slight differences, over a period of time, could lead us away from the original taste quality. The solution is to extend testing of potential standard to five times the usual test-length, 100 judgments, and to accept lots only where results are internally consistent and where the combined percent-correct lies close to 50%. Then we do have fair statistical assurance of identity.

Note that production must take the risk of having rejected, on the average of 1.4 times in 100, lots which are identical with the standard. There is a much greater, but unknown, risk of rejecting lots which differ in such slight degree that they would have no adverse effect on sales. Of course, in the final analysis limits are set, not on the basis of statistical theory alone, but also on the basis of what production can achieve, and at such a point that the cost of reblending, and the incident delay, do not become prohibitive. At the outset of our program limits were much wider than at present, but, under the strong motivation provided by the system, and aided by the definite information it could give, the production department did such a good job of process control that limits could be progressively narrowed.

Those who are adept in the field of statistical quality control are aware that, in general, control problems are not susceptible to rule-of-thumb solutions. Each plant, each process, may present a unique problem. The system of acceptance testing of blended whiskey described here is just that—a specialized solution to a specialized problem. However, it is quite likely that this method, and variants thereof, could find wide application in the food and beverage industries.



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DOES THE SHOE FIT—??

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Applying the Group Chart for $\overline{X}$ and R

D. F. BOYD

Quality Control Analyst, Detroit Engine Division, Kaiser-Frazer Corporation

IN APPLYING the $\overline{X}$ and R chart to control quality during production, situations are sometimes encountered where the number of individual charts required to cover adequately a critical operation is so great as to present a real obstacle to the practical use of this powerful method. A typical problem of this kind is presented when a single unit of product contains a number of identical or closely comparable characteristics which are all equally important from the standpoint of quality, but which must be properly considered as coming from separate "sub-processes". In such cases the group chart for $\overline{X}$ and R can often be utilized to great advantage in reducing charting labor and increasing ease of chart interpretation and analysis. An application from the writer's experience will be cited to illustrate these points.

A TYPICAL PROBLEM

A major automotive engine component processed at Kaiser-Frazer's Detroit Engine Division is the cylinder block sketched in Figure 1. A critical step in the processing of this part is the initial rough boring operation on the six cylinder bores of the block. This operation is performed on vertical boring machines of a type represented schematically in Figure 2. These six-spindle machines have two stations as shown,

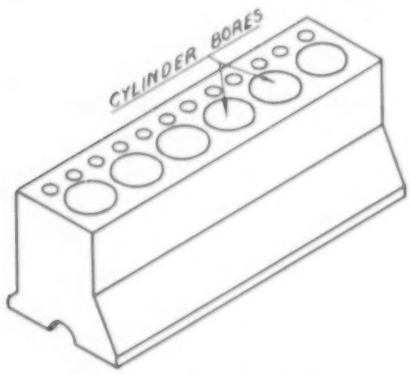

Figure 1—**Cylinder Block**

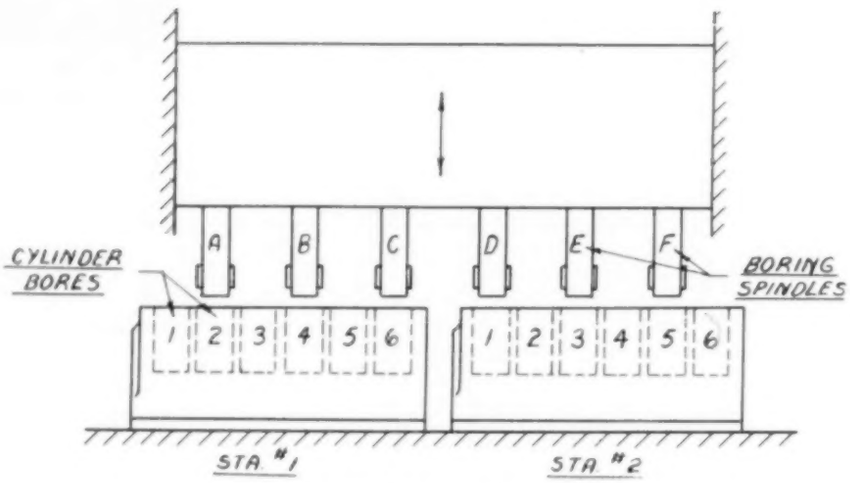

Figure 2—**Vertical Boring Machine**

and machine the six cylinder bores of a block in two passes. Cylinder Nos. 2, 4, and 6 are bored while the block is at station 1 and the remaining bores, Nos. 1, 3, and 5 are machined when the block is moved to station 2. The process control problem presented by this operation is that of charting cylinder bore diameter where each block contains six bores, all of equal size, and all of equal importance from a quality viewpoint.

A superficial examination of the problem might suggest the following charting procedure:

1. Consider each block a sample of 6 bores from the boring process.
2. Set up a single $\overline{X}$ and R chart on bore diameter for n = 6, $\overline{X}$ being the average of the bore diameters in a single block and R the difference between the largest and smallest diameter measurements.

Such a "solution", however, would in reality be no solution at all since a sample selected in this way would constitute a "systematic composite" and would not permit the calculation of valid 3-sigma limits for $\overline{X}$ and R. The following analysis of the boring operation reveals the reason for this.

From Figure 2 it may be seen that the six spindles are largely independent of each other with respect to their effect on cylinder bore diameter. This means that the machined diameter of each individual bore in the block actually reflects the performance of the corresponding individual boring spindle. As a result, the bores in a single block must properly be considered the product of six independent "sub-processes" rather than a single process. If the error is made of computing $\overline{X}$ and R from the bores of a single block, R will reflect variation between spindles as well as variation within spindles. Moreover, a single block is not a random sample of bores but instead is systematically composed so that the product of each spindle is represented in each sample. Accordingly, the maximum difference between any two spindles would always establish the range which would thus be systematically inflated. Since control limits for both $\overline{X}$ and R involve the average range they would be correspondingly spread by the biased values of R. Limits obtained in this way would show a state of control when it did not exist, and the purpose of the chart would be defeated.

OPERATION Rough Bore, Cylinder Bores

MACHINE West VARIABLE Bore dia.

n = 5 GAGE 0 = 3.245 UNITS = .001"

BORE →	1	2	3	4	5	6
BLOCK NO.1	+1	+2	+2	+3	+4	+2
↓ 2	+2	+4	+3	+4	+5	+4
3	+3	+3	+3	+3	+5	+6
4	+3	+2	+2	+4	+3	+3
5	+4	+1	+4	+4	+6	+6
Σx	13	12	14	18	23	21
$\bar{x}$	+2.6	(+2.4)	+2.8	+3.6	(+4.6)	+4.2
R	3	3	2	1	3	(4)

MIN $\bar{X}$ MAX $\bar{X}$ MAX R

Figure 3—**Inspection Data from One Sample Consisting of Five Cylinder Blocks**

To avoid the pitfall just described, it is necessary to separate the product of the six spindles for charting purposes. To accomplish this, conventional practice would require establishing an $\bar{X}$ and R chart for each of the six cylinder bores based on samples consisting of two or more blocks. Since two of the boring machines shown in Figure 2 are in use on the boring operation described, a total of twelve $\bar{X}$ and R charts would then be required to chart adequately the operation of rough-machining cylinder bores.

I believe the reader will agree that the prospect of maintaining twelve $\bar{X}$ and R charts on a single machining operation is enough to give pause to the most enthusiastic advocate of quality control by statistical methods. In addition to the considerable labor involved in maintaining the twelve charts, there is the problem of making a combined interpretation of so many separate charts with speed and accuracy. Even the matter of finding sufficient space for posting such an imposing array of charts near the operation presents difficulties. Happily, the group chart offers a means of escaping this dilemma without compromising the effectiveness of the control chart.

ORIGIN OF THE GROUP CHART

The group chart for $\bar{X}$ and R was developed by the British during World War II and was described in "A First Guide to Quality Control for Engineers", a British Ministry of Supply publication compiled by Dr. E. H. Sealy and issued in 1943. At the time of its introduction, the group chart was primarily intended for use with multiple spindle machines or batteries of similar machines where only one quality characteristic per unit of product was being considered. However, the method is equally applicable to charting a number of identical quality characteristics in a single unit of product and can, therefore, be applied to the cylinder block of Figure 1.

The group chart for $\bar{X}$ and R offers the following important advantages when applied to the cylinder boring operations described above:

1. The total number of charts required for charting the bor-operation is reduced from 12 to 2 (one group chart for each of two boring machines).
2. Each group chart summarizes in compact form the performance of an entire 6-spindle boring machine by calling attention only to the particular spindles producing extreme values of $\bar{X}$ and R, i.e. the ones most likely to require corrective action.

CONSTRUCTING A GROUP CHART FOR $\bar{X}$ AND R

In setting up a group chart, inspection data are accumulated in the same way as if individual $\bar{X}$ and R charts are to be kept on each of the quality characteristics. Sample size

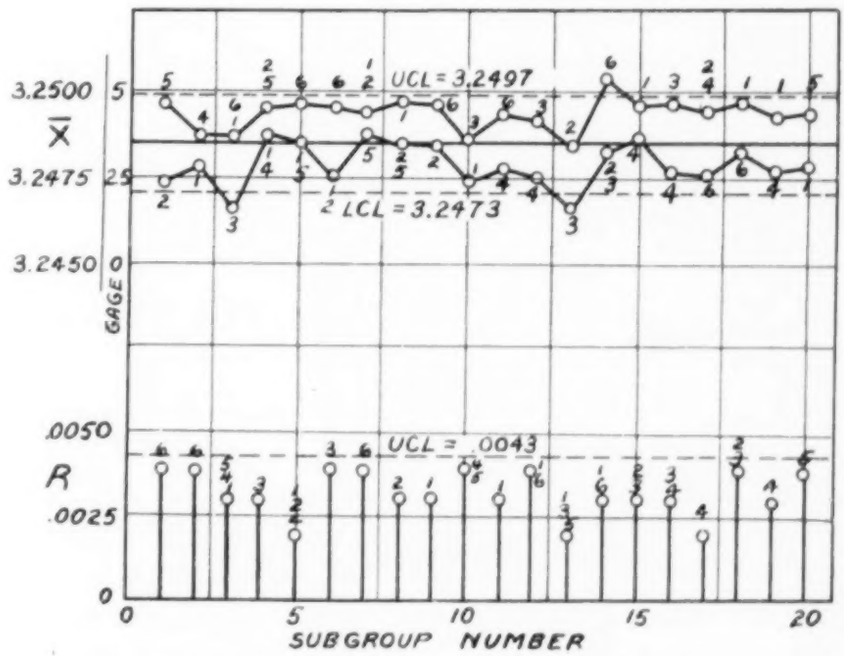

Figure 4—**Section of Group Chart for Cylinder Bore Diameter**

may be set at from 2 to 15 pieces although there is little or nothing to be gained by using a sample size larger than n = 5. The frequency with which samples are taken should be governed by the same considerations as for individual $\overline{X}$ and R charts. In the absence of special requirements a good general rule is to establish a sampling cycle such that between 5% and 10% of the product will be inspected in the periodic samples. Figure 3 shows inspection data obtained from a sample consisting of 5 cylinder blocks from the boring machine of Figure 2. Values of $\overline{X}$ and R are computed for each of the 6 cylinder bores as shown.

It is in the method of plotting $\overline{X}$ and R that the group chart departs from the conventional chart. In the group chart only the maximum and minimum values of $\overline{X}$ and only the maximum value of R are plotted. It is this omission of the intermediate values of $\overline{X}$ and R from the chart which so greatly simplifies interpretation of the mass of data involved.

A section of a group chart for the cylinder boring operation is given in Figure 4. The first set of points for $\overline{X}$ and R on this chart are taken from the sample data of Figure 3 and show the method of plotting extreme values. It will be noted that numbers designating the cylinder bore or bores producing the plotted values are recorded immediately above or below each point.

Control limits for a group chart are obtained by the same method used for the conventional $\overline{X}$ and R chart. However, in computing the $\overline{\overline{X}}$ and $\overline{R}$ *all* values of $\overline{X}$ and R are used. For example, while only the extreme values from the sample data of Figure 3 were plotted on the chart, all six values of $\overline{X}$ and R would be used in calculating $\overline{\overline{X}}$ and $\overline{R}$ for the purpose of obtaining control limits. The conventional ASTM control limit factors A_2 (used for obtaining limits for $\overline{X}$) and D_3 and D_4 (used for obtaining limits for R) are selected according to sample size and applied to the group chart just as they are to the conventional chart for $\overline{X}$ and R. It should be remembered that the sample size is the number of units of product in each sample and not the number of quality characteristics appearing in a single unit of product. For example, in the data of Figure 3, sample size is determined by the number of cylinder blocks, not the number of bores in a single block.

INTERPRETATION OF A GROUP CHART

Interpretation of a group control chart is similar to that of a simple $\overline{X}$ and R chart. Since group chart control limits are calculated in the same way as for a conventional chart they have the same significance. If the "group-process" has attained an initial state of statistical control, a sample yielding extreme values of $\overline{X}$ and R within control limits may be accepted as evidence that all the sub-processes of the group process are continuing in control. When a point falls outside control limits it may be interpreted as significant evidence that a shift has occurred in one or more of the sub-processes being plotted. In such a case the particular sub-process requiring corrective action will be indicated by the identifying number recorded with the out-of-control point. In the case of the cylinder boring machine this means that the particular spindle and boring cutter exhibiting an out-of-control condition can be identified

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immediately and corrected. For example, the first point falling outside control limits in the chart of Figure 4 is identified with cylinder bore No. 3. Reference to Figure 2 will show that spindle E of the boring machine is the one which should be checked.

If all sub-processes plotted on a group chart are operating at the same controlled level, the identifying numbers recorded with the plotted points may be expected to appear in a random fashion. Conversely, if the same sub-process consistently yields extreme values near the same control limit, it may be interpreted as strong evidence of a shift in the sub-process even before a point falls outside control limits.

ADDITIONAL APPLICATIONS

The application of a group chart to the rough cylinder boring operation which has been described in some detail is one of a number of similar control charting problems to which the group chart has been applied successfully at the Detroit Engine Division. Other applications have been made in machining of cylinder block main bearing bores, cam bearing bores and crankshafts. All of these operations present similar charting problems in that they involve several identical quality characteristics which appear in one unit of product but which reflect the performance of independent sub-processes.

CONCLUSION

To summarize, the writer has found the group chart for $\bar{X}$ and R an effective and economical device for charting machining operations in which the use of conventional $\bar{X}$ and R charts would impose a prohibitive burden of paper work as well as an obstacle to rapid overall evaluation of "group-processes" of the type described.

Reference

E. L. Grant, *Statistical Quality Control*, pp. 192-196.

Quality Control in the Forging Industry*

D. G. BROWNE

Sales Manager, The Broderick Co., Muncie, Indiana

WE at The Broderick Company received our introduction to quality control through Hugo A. Weissbrodt, who is in charge of the Fort Wayne operations of International Harvester, and in his plant, applies quality control to the assembling of trucks, to the machining of parts for those trucks, and to the forging of many of the parts which enter those machining and assembly lines. In seeing quality control in his plant it was only natural that our interest should center in his use of this new technique in the forge plant. It was natural, also, that our own early thinking about quality control should have been conditioned by the impressions gained in that visit. At that time none of us knew a double bar X from an alphabet noodle, but we did make an early application which was logical and simple and has proven to be profitable. More recently, we have taken a slightly different course. Both of these applications will be discussed in this paper, but first we shall describe what a forging is and how it is made.

*Condensation of a paper given before the Muncie Section, ASQC, August 25, 1949

FORGING OPERATIONS

Even though forging is a highly specialized technique, it has two basic characteristics which are also found in many other industries. These characteristics are: we change the dimensional but not the physical properties of our raw material and we use more raw material than we need, selling the overage as scrap. Similar conditions are encountered in many other processes from metal stamping to a tailor made suit.

Forgings are made on three different types of equipment: hammers, upsetters and presses, mentioned in order of their development. We shall mention the upsetter only briefly. It is a machine which holds a piece of round bar stock and forms, on one end, an enlarged section of the size and shape which are dictated by the corresponding impressions in the forging dies. It is very similar in its operation to the smaller version of the same machine which puts heads on nails, bolts and rivets, and, in fact, in the forging industry an upsetter is usually referred to as a header. And just as a nail is mostly nail and very little head, so the average product from an upsetter is mostly bar stock and very little forging. For this reason, we have made no application of quality control to our upset operation and, in my opinion, we will not do so for a long time.

The time honored method of making forgings—one dating back in a simpler form to the middle ages—is the steam or board hammer, and more recently it has been supplemented, but not in any sense replaced, by the forging press. While these two machines are radically different, they are fundamentally the same in principle in that they both bring together two steel die blocks, each of which carries an impression sunk into its meeting surface. The impact or pressure of their contact acts on and shapes a billet of steel or non-ferrous metal, heated to a plastic state, into the shape of the impressions, thus producing the forging. In the case of the hammer, the work is done through impact, and it should be noted that the operator, by varying the number and intensity of the blows, has in his hand a useable tool as much under his control as a screwdriver. Thus the human element is a vital factor

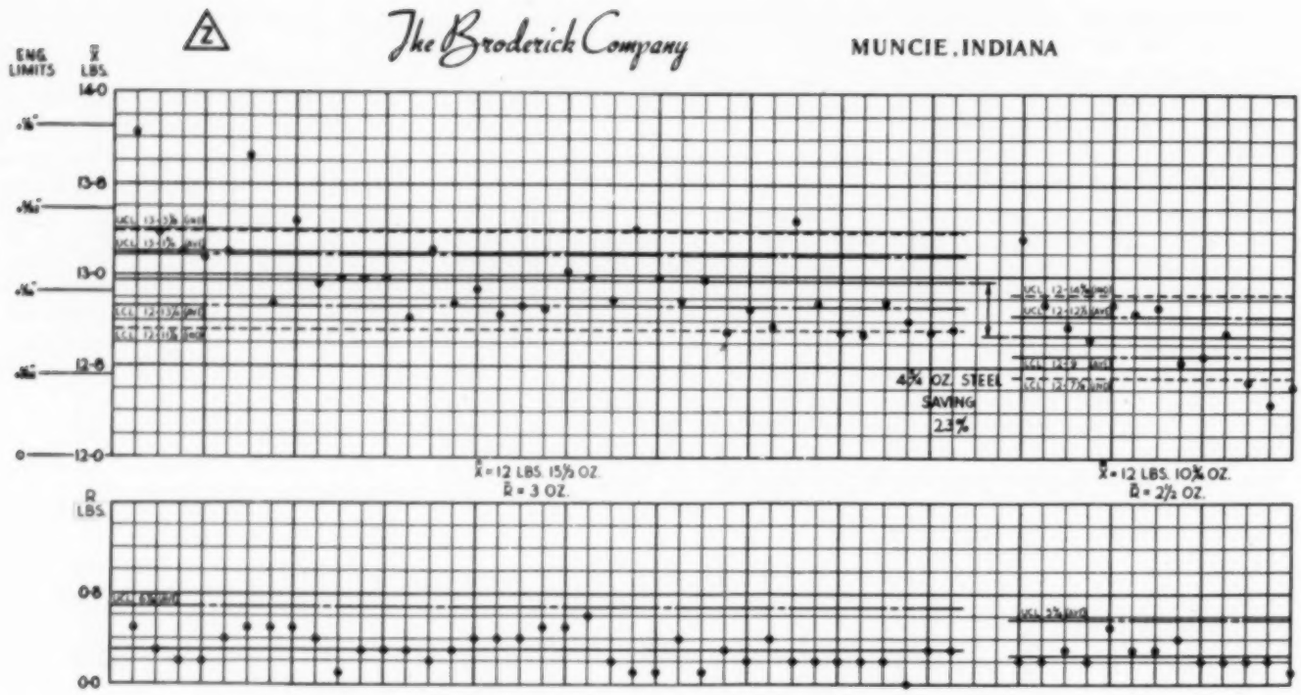


Figure 1— **Typical Control Charts on Maxi-Press Production of Ring Gears.** Each Plotting represents the average and range of one sample of 4 taken each hour. Approximately 1% sampling. These charts cover the production of about 20,000 forgings.

in hammer operation. In the case of the press, the work is done by pressure and is completed in one blow. While the machine is subject to adjustment, its operator can do no more than send it through one cycle by pushing the control button. Thus the press is largely devoid of the personal element in operation, and, if its adjustment is not disturbed, is capable of close performance.

At first glance, it would appear that forging is a simple technique: make sure that the impressions in the dies are the right shape and size, put in enough steel to fill them, and you have a forging. Actually however, it is not quite so simple. The surfaces of the impressions wear away during forging, thus enlarging the cavity and producing a forging which slowly increases in size and weight throughout the life of the dies. This variance must be held within the engineering limits set up by the customer, and thus is established the life of the die between successive re-cuttings of the impression, or "re-sinkings" as the term is used in the industry. Beyond all this, it is commercially impossible to put in "the right amount of steel". Steel is fed to a forging furnace in the form of billets—small sections of a bar of the correct grade, shape and dimension, cut into lengths, each of which approaches the proper weight. As steel is purchased today, its outer surface is "conditioned" before shipment to remove defects and where conditioning is severe there is a heavy removal of metal, thus reducing the cross-sectional area and, consequently, the weight of any billet cut from such a bar. Because of this condition, steel is considered commercially acceptable if its weight varies no more than 5% above and 5% below the theoretical value. Beyond this consideration, and further compounding the variable, it is impossible to saw or shear billets in commercial operations closer than 1/16" or at best 1/32" to a desired length.

In practice, it is the universal custom to use a billet larger than that required to make the forging and to trim off the excess metal, known as "flash", from the finished part. In order to make room for this excess metal to gather, a shallow but wide groove is cut in each die completely surrounding the impression. This flash groove is intentionally made shallow in order that resistance may be created to the flow of metal into it, thus forcing the plastic metal to fill the impression first. In order to provide a further safeguard for the accommodation of excess stock, a second deeper channel, known as the "gutter", is cut in the face of each die, completely surrounding the flash groove.

To be acceptable, forgings must have dimensions which lie within the tolerances specified by the customer. Certain of these dimensions are produced solely by the dimensions in the impression in one of the two dies. Others, however, which span the full thickness of the forging, are created by the dimensions of the impressions in both dies and also by the amount the dies come together. Take, for example, a simple sprocket with a hub on each side of the central web. This would be forged flat so that the flash would surround the outside of the sprocket, and the plane at which the two dies meet would pass through the center of the hub and the web. In such a forging, all diameters in the sprocket would be established by the dies and this would also be true of the height of the hub above the web. However, the thickness of the web itself and the length through the hub would be determined by the depth of the die impressions and also by the amount the dies come together. This latter distance is capable of control—by adjustment in the press and by manipulation in the hammer. Thus, forgings can be produced to a

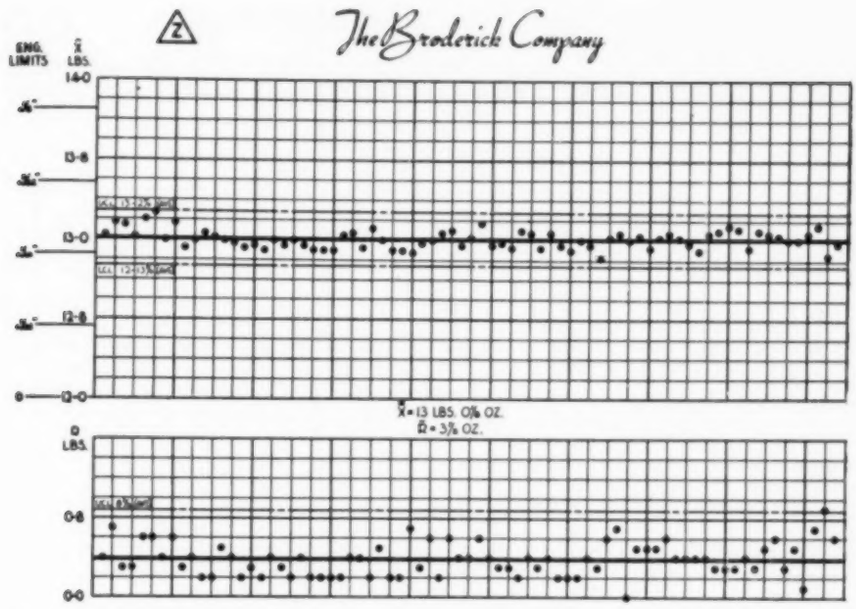


Figure 2—**Control Charts of 100% Sampling of 300 Ring Gears Taken During the Run Shown on the Charts in Figure 1.**
These forgings were made from billets held to 4 oz. variation. This entire chart covers a time interval shorter than one plotting in Figure 1.

definite dimensional range, or, to express it differently, to a definite weight range.

FORGING DEFECTS

There are certain forging defects which are commonly encountered in production. One of the simplest forms is found when the billet is either too light in weight or is of the proper weight but is badly centered in the impression, thus producing a forging which has not completely filled the die. This is known as a "not-filled" forging. Again, when the dies are set up in the hammer or press in such a way that one die is not directly in line with the other, the forgings so produced will have an eccentricity existing between the two halves which represent the two impressions. Such a forging is known as a "mis-match". In producing any forging by any method the plastic metal should flow smoothly into the impression, thus forming a homogeneous mass. At times, due to any one of a number of reasons, one portion of the plastic metal will flow ahead of the balance and be folded over against the main body of the metal in filling the die. Because of the constant presence of a light scale on the surface of all forgings in process, the metal at such a lap does not weld together and under subsequent machining the lap would peel out forming a depression. This condition in a forging is known as a "cold-shut". When billet heating is conducted at too high a temperature or for too long a period or under improper atmospheric conditions, the resulting scale cannot be fully removed before forging, and this excess scale, when finally removed from the surface of the forging into which it had been forced, leaves pits in the surface which may be deep enough to cause rejection. Such a forging is known as a "scaly" forging. Finally, the surfaces of commercial forging bars sometimes contain minute cracks which, under certain working conditions, open up into seams in the outer surface of the finished product, frequently to such a depth as to cause rejection. Such forgings are called "seamy".

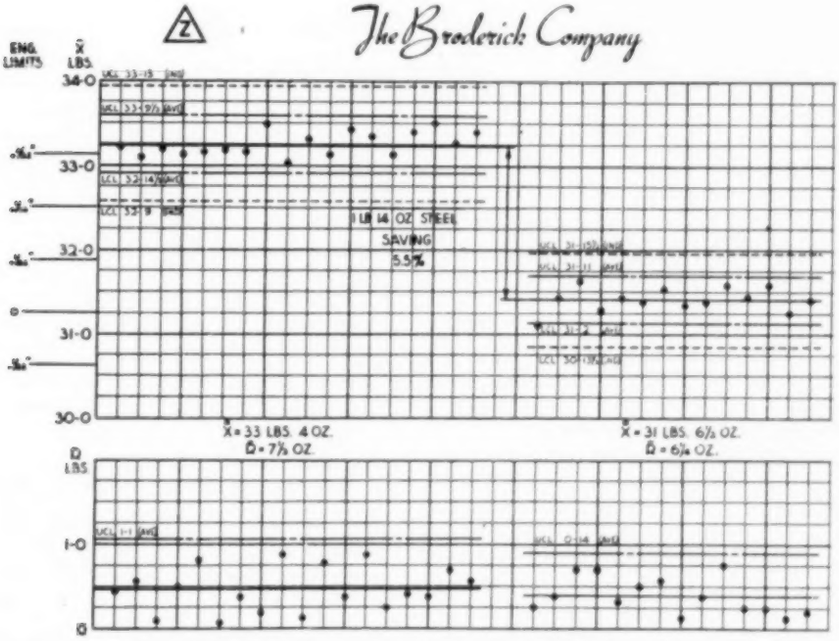
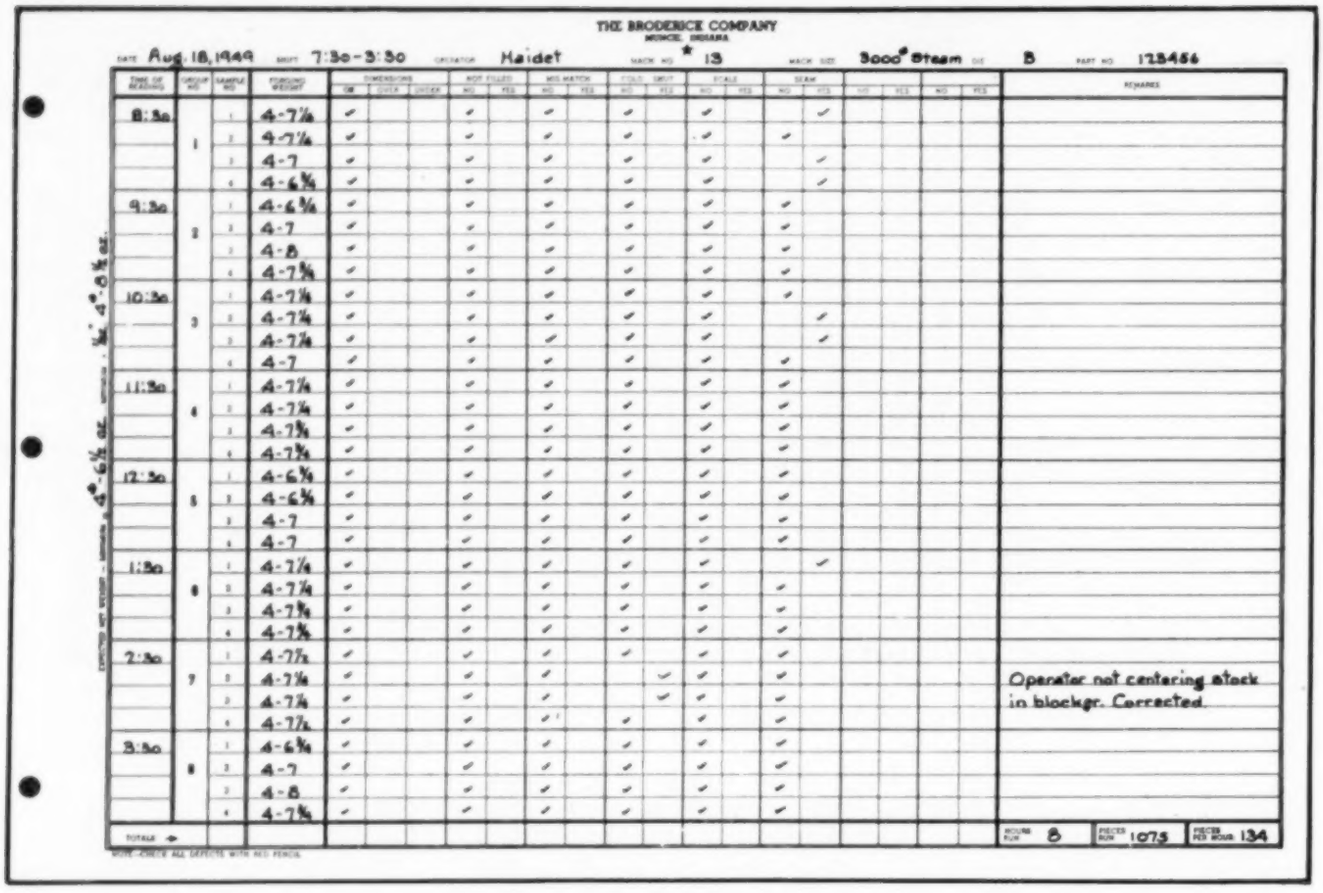


Figure 3—**Typical Control Charts on Hammer Production of Ring Gears.**
One sample of four taken hourly and the average and range plotted. Note weight reduction obtained through redesign of dies to approach lower Engineering limits.

FORGING INSPECTION

Now a word about inspection. Our company follows the pattern common to the industry in having two types of inspection—hot and cold. A Hot Inspector is responsible for the quality of the output of a certain number of pieces of equipment. He draws samples of hot forgings from each of these machines at regular intervals and inspects them for common defects as well as for conformance to dimensions. It should be noted that in checking dimensionally he uses a shrink rule. In many cases the weight of a forging is a direct criterion of its dimensions, so that if a forging weighs within limits he knows that it is also dimensionally within limits. Weight, as a matter of fact, has become our



THE BRODERICK COMPANY
MUNCIE, INDIANA

DATE Aug. 18, 1949 SHIFT 7:30-3:30 OPERATION Haidet MACH. NO. * 13 MACH. SIZE 3000# Steam DIE B PART NO. 123456

TIME OF READING	GROUP NO.	SAMPLE NO.	FORGING WEIGHT	DIMENSIONS OK	DIMENSIONS OVER	DIMENSIONS UNDER	HOT FILLET NO	HOT FILLET YES	MIS-MATCH NO	MIS-MATCH YES	FOLD SHUT NO	FOLD SHUT YES	SCALE NO	SCALE YES	SEAM NO	SEAM YES					REMARKS
8:30	1	1	4-7⅛	✓			✓		✓		✓		✓			✓					
		2	4-7¼	✓			✓		✓		✓		✓		✓						
		3	4-7	✓			✓		✓		✓		✓			✓					
		4	4-6¾	✓			✓		✓		✓		✓			✓					
9:30	2	1	4-6⅝	✓			✓		✓		✓		✓		✓						
		3	4-7	✓			✓		✓		✓		✓		✓						
		2	4-8	✓			✓		✓		✓		✓		✓						
		4	4-7⅝	✓			✓		✓		✓		✓		✓						
10:30	3	1	4-7⅛	✓			✓		✓		✓		✓		✓						
		3	4-7¼	✓			✓		✓		✓		✓			✓					
		2	4-7⅛	✓			✓		✓		✓		✓			✓					
		4	4-7	✓			✓		✓		✓		✓		✓						
11:30	4	1	4-7⅛	✓			✓		✓		✓		✓		✓						
		2	4-7¼	✓			✓		✓		✓		✓		✓						
		3	4-7⅜	✓			✓		✓		✓		✓		✓						
		4	4-7⅜	✓			✓		✓		✓		✓		✓						
12:30	5	1	4-6⅜	✓			✓		✓		✓		✓		✓						
		3	4-6⅜	✓			✓		✓		✓		✓		✓						
		2	4-7	✓			✓		✓		✓		✓		✓						
		4	4-7	✓			✓		✓		✓		✓		✓						
1:30	6	1	4-7⅛	✓			✓		✓		✓		✓			✓					
		2	4-7¼	✓			✓		✓		✓		✓		✓						
		3	4-7⅜	✓			✓		✓		✓		✓		✓						
		4	4-7⅜	✓			✓		✓		✓		✓		✓						
2:30	7	1	4-7⅛	✓			✓		✓		✓		✓		✓						
		3	4-7¼	✓			✓		✓			✓	✓		✓						Operator not centering stock in blocker. Corrected.
		2	4-7¼	✓			✓		✓			✓	✓		✓						
		4	4-7⅛	✓			✓		✓		✓		✓		✓						
3:30	8	1	4-6¾	✓			✓		✓		✓		✓		✓						
		3	4-7	✓			✓		✓		✓		✓		✓						
		2	4-8	✓			✓		✓		✓		✓		✓						
		4	4-7⅝	✓			✓		✓		✓		✓		✓						
TOTALS →																					HOURS RUN 8 PIECES RUN 1075 PIECES PER HOUR 134

NOTE—CHECK ALL DEFECTS WITH RED PENCIL

LIMITS OF WEIGHT — MINIMUM 4#-6½ oz. MAXIMUM 4#-8½ oz.

Form D

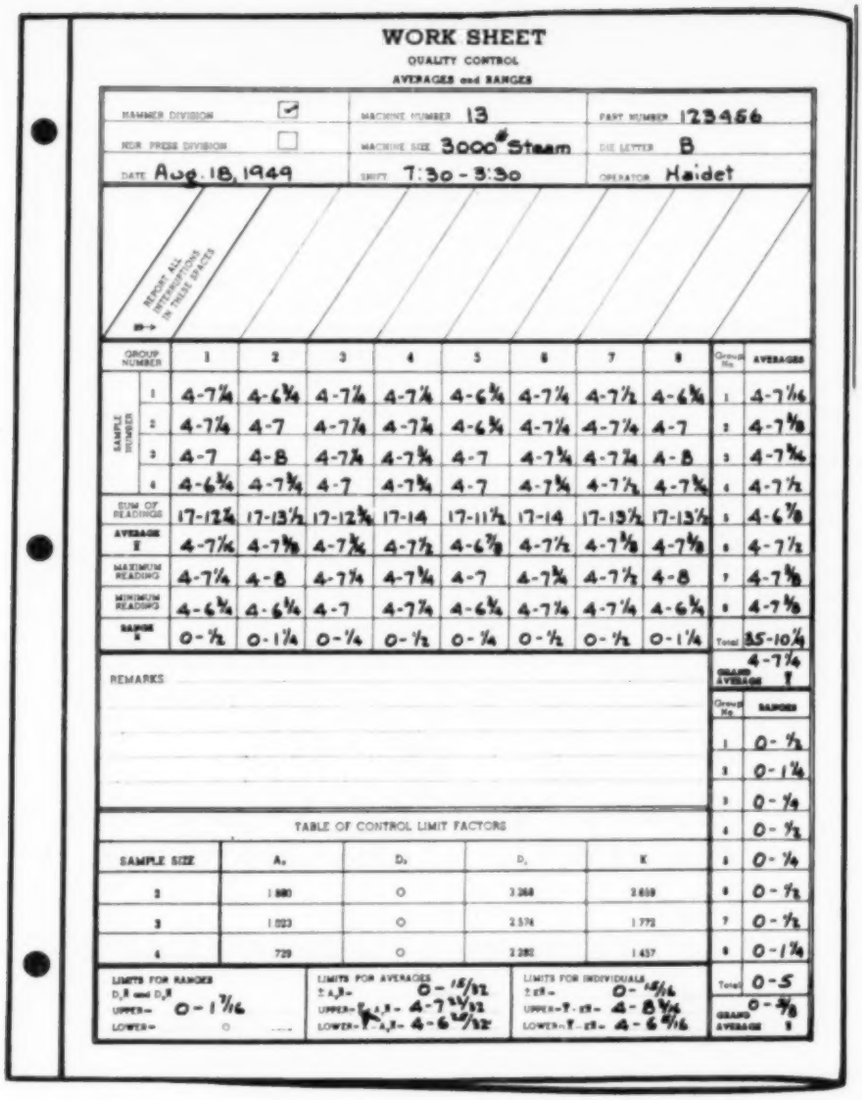
most frequently used variable in applying quality control. It is within the Hot Inspector's authority to shut down any operation which, in his opinion, is producing below the acceptance level. A Cold Inspector examines all production immediately ahead of shipment, looking for any rejectable defect and checking for straightness or any other quality which may be demanded by the customer. All rejects from cold inspection are either re-worked or scrapped.

APPLICATION OF SQC TO A FORGING PRESS

In looking for an obvious application of quality control to our problem, it seemed simplest to search for a means of economizing in steel. Two means of economizing are available. First, the dimensions of any forging are permitted to float between upper and lower engineering limits set by the customer. Thus, forgings may be of any weight between heavy and light extremes which correspond to these dimensional limits. Secondly, the amount of extra metal trimmed off as flash may range from a maximum which could approach absurdity down to a minimum where too little is left for a good trimming operation. The greatest economy is effected when these two variables are at the lowest point consistent with sound commercial practice.

When our interest in quality control was first awakened, we were in almost continuous production of ring gear forgings on one of our forging presses. Our first application consisted in tabulating the weights of averages of four hourly samples of finished ring gears produced under conditions identical with those which had existed previously. These readings are shown in the left hand portion of Figure 1. On this, as well as on the other two similar charts, our use of the figure 12—8 refers to twelve pounds eight ounces, and the fractions shown to the left of the chart are the fractional inches in dimensions which constitute the engineering limits set by the customer as allowable diviation from his mean. When the pattern representing past performance had been thoroughly established, we took our first step in reducing forging weight by bringing the dies closer together and by making a corresponding reduction in the weight of the billet in order not to crowd the press with excessive flash. Average weights of four hourly samples under this new setting are shown on the right hand side of Figure 1. A reduction of 4¾ ounces in the weight of the forging itself is shown as being the difference between the two average lines on Figure 1, and the total saving in weight of steel put into the job in billet form actually amounted to 8 ounces, or a little over 3 cents per forging. At the same time, Figure 1 shows that the lower control limit for individual forgings has not yet, at this lower weight, approached dangerously close to the low engineering limit shown at the left of the chart. Later changes in machine setting, die design, and billet weight increased our economies to a final five cents a forging.

Early in the run which is recorded in Figure 1, it became apparent that the range in four samples at any giv-



WORK SHEET

QUALITY CONTROL

AVERAGES and RANGES

HAMMER DIVISION ☑ | MACHINE NUMBER 13 | PART NUMBER 123466

HDR. PRESS DIVISION ☐ | MACHINE SIZE 3000# Steam | DIE LETTER B

DATE Aug. 18, 1949 | SHIFT 7:30 - 3:30 | OPERATOR Haidet

REPORT ALL INTERRUPTIONS IN THESE SPACES →

GROUP NUMBER		1	2	3	4	5	6	7	8	Group No.	AVERAGES
SAMPLE NUMBER	1	4-7¼	4-6¾	4-7¼	4-7¼	4-6¾	4-7¼	4-7½	4-6¾	1	4-7 1/16
	2	4-7¼	4-7	4-7¼	4-7¼	4-6¾	4-7¼	4-7¼	4-7	2	4-7 3/8
	3	4-7	4-8	4-7¼	4-7¾	4-7	4-7¼	4-7¼	4-8	3	4-7 5/16
	4	4-6¾	4-7¾	4-7	4-7¾	4-7	4-7¾	4-7½	4-7¾	4	4-7½
SUM OF READINGS		17-12¾	17-13½	17-12¾	17-14	17-11½	17-14	17-13½	17-13½	5	4-6 7/8
AVERAGE ȳ		4-7 1/16	4-7 3/8	4-7 5/16	4-7½	4-6 7/8	4-7½	4-7 3/8	4-7 3/8	6	4-7½
MAXIMUM READING		4-7¼	4-8	4-7¼	4-7¾	4-7	4-7¾	4-7½	4-8	7	4-7 3/8
MINIMUM READING		4-6¾	4-6¾	4-7	4-7¼	4-6¾	4-7¼	4-7¼	4-6¾	8	4-7 3/8
RANGE R		0-½	0-1¼	0-¼	0-½	0-¼	0-½	0-½	0-1¼	Total	35-10¼
										GRAND AVERAGE	4-7¼ ȳ

REMARKS

Group No.	RANGES
1	0-½
2	0-1¼
3	0-¾
4	0-½
5	0-¼
6	0-½
7	0-½
8	0-1¼
Total	0-5
GRAND AVERAGE	0-5/8 R

TABLE OF CONTROL LIMIT FACTORS

SAMPLE SIZE	A_2	D_3	D_4	K
2	1.880	0	3.268	2.659
3	1.023	0	2.574	1.772
4	.729	0	2.282	1.457

LIMITS FOR RANGES D_3R and D_4R: UPPER= 0-1 7/16; LOWER= 0

LIMITS FOR AVERAGES $\bar{x} \pm A_2\bar{R}$: UPPER= 4-7 21/32; LOWER= 4-6 11/32

LIMITS FOR INDIVIDUALS $\bar{x} \pm K\bar{R}$: UPPER= 4-8 9/16; LOWER= 4-6 7/16

Form E

en time was exceedingly small, but that the actual weight was inclined to float through a much wider spread over a day's or a week's operation. Our product was at all times safely within tolerance but there was a lack of weight and dimensional consistency which was disturbing. We knew that the weight of the forging was directly affected by the variation in the weight of the billet, as well as by the variable factors in the forging operation itself, and we were interested in determining the effect of these factors individually. Accordingly, during the run, a selected group of 300 billets was used, each of which, after careful and laborious weighing of all available billets, was found to fall within a range of two ounces over and two ounces under a predetermined weight. These 300 billets were forged consecutively and 100% sampled, with the results shown in Figure 2, in plottings of averages of four. The contrast between this and the previous chart is striking. In comparing these two charts, it must be remembered that the entire run of Figure 2 represents a time interval less than one dot on Figure 1. It is evident that, when fed a uniform product, the press works within extremely close limits, at any given short period of time. With this fact established, the charts in Figure 1 were re-examined, and it was found that all vagrant plottings on the high side represented readings taken at the beginning of a shift or following a lapse in operation due to die changes or other machine adjustments. During the preceding down time, the temperature of both the furnace and the dies had lowered and, on starting up again, we were forging less plastic steel with cold equipment, naturally producing an overweight forging.

The various factors which contribute to such wide-spread operation have since been studied critically and we have reconciled ourselves to the fact that they are all correctable, but not under normal operating conditions. It would appear that we will always have, in the forging press, an operation which stays well inside engineering limits but remains consistently out of control. It is unfortunate that conditions cannot be maintained as indicated in Figure 2. Were this the case we could adjust to a point where forgings fell just above the low limit and be assured of maximum economy with little danger of violating set tolerances. However, even under normal variation, economies have been effected in a large number of cases, similar to and equalling the profit reflected in Figure 1.

APPLICATION OF SQC TO HAMMER FORGING

The hammer presents a completely different problem. Functioning as it does through impact, it is understandable that no hammer can be maintained in the same nice adjustment that is possible with a press. To compensate for this, much of the result achieved by a hammer is due to the operator rather than to the machine and, in consequence, a full run on the hammer will yield a more uniform product than will a full run on the press. We have capitalized on this uniformity in a great many cases, one of which is illustrated in Figure 3, which again plots averages of samples of four. This chart represents a large gear on which we have been in intermittent production for a long time. In starting quality control on hammer operation we selected our next run on this gear as a trial and recorded weights which developed out of machine settings the same as those in effect in our last previous production. These weights are shown on the left hand side of Figure 3, varying around a center of 33 pounds 4 ounces, in contrast with an upper limit of 33 pounds 2 ounces. After a run of sufficient length to establish the pattern, we reduced the volume of the impression by planing off the meeting surface of each die and lightened the weight of the billet correspondingly. The net result is shown on the right hand side of Fig-

ure 3 where it is seen that the forgings average approximately 31 pounds 6 ounces, or a saving in weight of 1 pound 14 ounces. There is still some further lightening possible beyond that shown in Figure 3, and this has been accomplished since these readings were taken. It should be remembered that the 1 pound 14 ounce saving shown is for the net forging weight only. Our actual saving in the amount of steel put into this job in billet form was 3 pounds 8 ounces, or an equivalent of 21 cents.

DATA AND WORKSHEET FORMS USEFUL FOR SQC IN FORGING OPERATIONS

Recently, we have taken a new approach to quality control through the use of a tabular sheet of which Form D is a completed example. This form hangs in a transparent envelope beside the forging equipment and, each hour, is removed so that the results of checking the previous hour's work may be entered, and then returned to the envelope. It will be noted that the vertical columns are arranged to record weight and to check against normal defects. Weight is the only variable and the theoretical weight at upper and lower engineering limits is shown at the left of the form. All other columns show defect attributes. When this form is completed it is folded to form a letter size sheet and the weights are transferred to the reverse side where averages and ranges are calculated. This reverse side, with the figures entered, is shown in Form E.

This new form has many advantages. It presents an hourly record to the operating crew, thus introducing the incentive and rivalry element into production. It provides an instant warning when any type of defect becomes repetitive, and results in corrective measures or in shutting down the job. It supplies weight figures which, at any time, can be converted into a control chart. Finally, it gives very valuable information to the cold inspection department, permitting these inspectors to relax vigilance on certain types of defects which have not shown up in hot inspection and to concentrate their search for forgings showing those defects which prevailed during production.

CONCLUSION

A closing comment seems appropriate. We firmly believe that quality control can be profitable to the forging industry by eliminating certain losses now suffered through the use of more steel than is needed. Our own experience indicates that this is the most fertile source of economy open to us. Finally, it is our opinion that the lighter and more uniform forging made possible by quality control will be appreciated by the machining industry and we hope that, in time, it will command a premium price.

The Effect of One-Sided Truncation on the Average of a Normal Distribution

IRVING B. ALTMAN

Quality Control Statistician, Bureau of Ships, Department of the Navy

IN the inspection of an item at a Naval Ordnance Establishment, the specification requirement called for the lot average of a particular electrical characteristic to be equal to or greater than a certain value M. Since the inspection lot contained approximately 3000 units, sampling inspection by variables was utilized in the lot-by-lot evaluation of this electrical characteristic. Where the variables acceptance criterion was not satisfied and the lot was rejected, the problem arose as to the approximate value of the characteristic below which a minimum number of units would be screened out with the remaining units averaging at least the specification minimum of M and thus be accepted on resubmission.

Figure 1 gives a graphical solution of the increase in the average of the resulting truncated Normal Distribution depending on the percent of the Normal Distribution truncated. The appendix to the paper presents the mathematical derivation and computation of the various circled points in Figure 1.

A hypothetical example will illustrate the procedure in determining the approximate truncation value for a lot not meeting the specification average.

Suppose that a random sample of 200 variable measurements of condenser leakage gives a mean of $\bar{X} = 800$ megohms and that the standard deviation of this electrical characteristic as determined from experience is 200 megohms. The specification requirement for the lot average is assumed to be 900 megohms minimum. Since the difference between the average of the sample and the lot average minimum specification is too large to attribute to sampling variation, it is necessary to screen out the low values of the condenser leakage so that the remaining units will average 900 or more megohms. The 95% confidence limits for the lot average are computed from the formula $\bar{X} \pm (1.96\sigma)/\sqrt{n}$ and found to be 772 to 828 megohms. An increase of 128 megohms is necessary to bring the lower confidence limit of the lot average (772) to the 900 megohm minimum requirement.

Referring to Figure 1 and using the value of sigma determined from experience (200 megohms), an increase of 128 megohms corresponds to $128/200 = .64\sigma$ on the vertical axis. Reading from this point over to the curve and thence to the horizontal axis, we find a 39% truncation required. Entering a Normal Area Table, the normal deviate (K) below which 39% of the distribution lies is

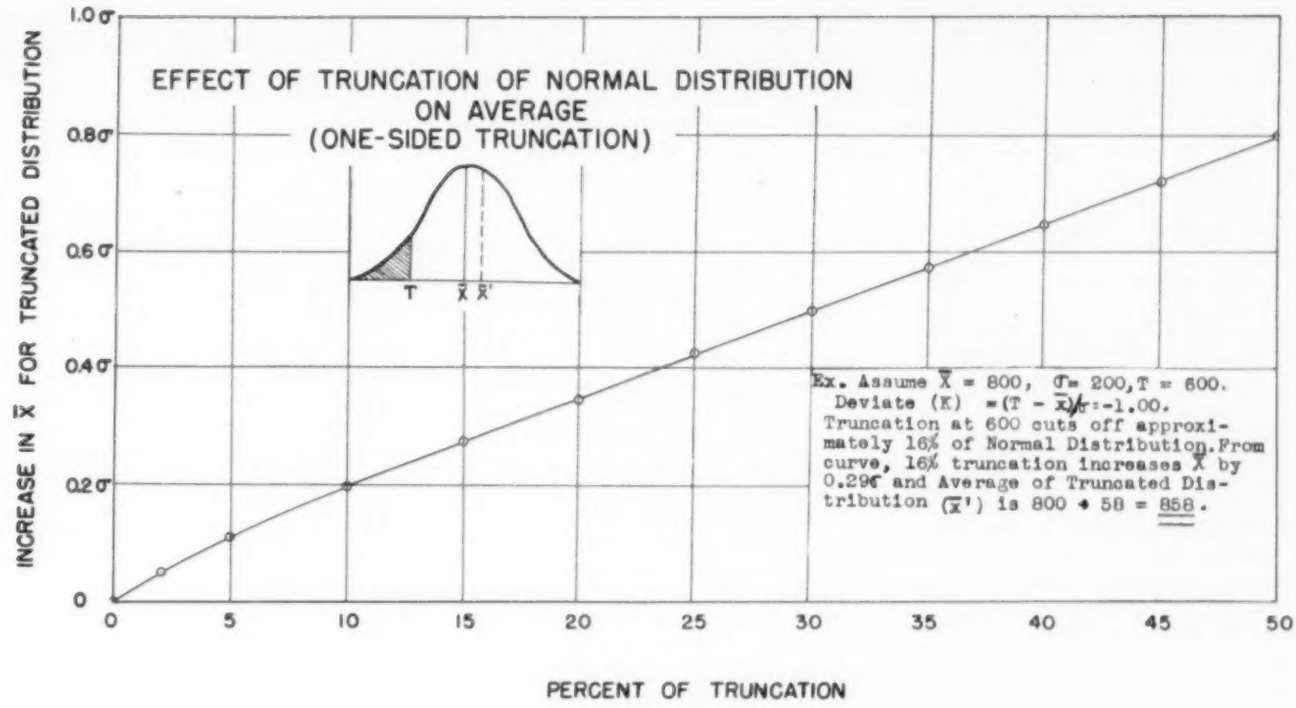


Figure 1

found to be —0.28. Substituting in the formula K = (T-772)/200 = —0.28, the truncation value (T) is found to be 716 megohms.

Hence, if the lot mean were originally at 772 megohms, truncation at 716 megohms would be expected to raise the mean of the remainder of the lot to 900 megohms.

APPENDIX

The centroid ($\bar{X}'$) of a normal curve truncated at T is equal to

$$\frac{1}{\sqrt{2\pi}}\int_K^\infty u e^{-u^2/2}\,du \Big/ \frac{1}{\sqrt{2\pi}}\int_K^\infty e^{-u^2/2}\,du$$

where $K = (T - \bar{X})/\sigma$. Upon integration of the numerator, the formula becomes

$$\bar{X}' = \frac{1}{\sqrt{2\pi}} e^{-K^2/2} \Big/ \frac{1}{\sqrt{2\pi}}\int_K^\infty e^{-u^2/2}\,du$$

The numerator is the normal curve ordinate at K and the denominator is the area under the normal curve from K to ∞. They may be evaluated by using tables of Normal Curve Ordinates and Areas.

To show how points on the curve in Figure 1 were computed, consider a 5% truncation of the left tail area for which normal curve tables give the deviate K = —1.645 and the ordinate at this value of K as .1032. Then $\bar{X}' = (.1032)/.95 = .1086$ in units of the standard deviation of the untruncated normal curve. Therefore, .1086σ would be the increase in the average of the untruncated normal curve because of a truncation of 5%. The other circled points of Figure 1 were computed in like manner.

References

"Tolerances—Additive or Pythagorean?" Acton and Olds, *Industrial Quality Control*, Nov. 1948, pp.6-12.

"A Note on Truncated Distributions". A. C. Cohen, Jr., *Industrial Quality Control*, Nov. 1949, p.22.

Book Reviews

A. C. Cohen, Jr., *Editor*

EXPERIMENTAL DESIGNS

William G. Cochran & Gertrude M. Cox; John Wiley & Sons, Inc., 1950. 454 + ix pp. $5.75. Review by Frank E. Grubbs, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland.

Correspondence and suggestions concerning book reviews should be sent to:
Professor A. C. Cohen, Jr.
Department of Mathematics
University of Georgia
Athens, Ga.

During the past twenty odd years great strides have been made in experimental techniques and scientific analysis of data, particularly in agriculture and biology. These advances have stemmed from the basic work in the design and analysis of scientific experiments by R. A. Fisher, Frank Yates, and others. Accomplishments to date are due largely to significant advances in statistical methodology and the relating of statistical models to problems which require this type of treatment. *Experimental Designs*

gives a systematic treatment of the more important and useful experimental arrangements or plans and goes far beyond simply bringing together the pay-off of pertinent papers and other recorded accomplishments which heretofore were scattered widely throughout statistical literature. The book takes into account many of the major problems related to experimentation and gives a clear and concise account of the reasoning behind the experimental arrangements in order that the results of one's endeavor will not be vitiated.

The authors of *Experimental Designs* are well qualified to write this book. They have had not only considerable experience in the field of experimental statistics but have made outstanding contributions to both the theoretical developments and the statistical treatment of data for a sound analysis of results. It is believed that due to the particular character of *Experimental Designs*, the advent of this book will effect considerable progress toward putting experimentation in all fields of endeavor on a scientific basis. The experimental arrangements and plans covered in the book carry directly over into the various engineering fields with only minor, if any, modifications; it can be said that the various fields of engineering have long had an urgent need for the procedures covered in the book.

A paper wrapper to the book has the following annotation:

> "A guide to better-planned, more accurate experiments. The authors present plans for 150 of the most useful experiment designs, point out their advantages and limitations, and provide detailed instructions for using each of them."

The reviewer considers that this is an under-statement. After introductory chapters which present very convincihg arguments for the scientific design and statistical analysis of experiments, the book covers the following very useful and practical experimental arrangements: completely randomized designs, randomized block designs, Latin square designs, cross-over designs, Graeco-Latin square designs, factorial experiments along with principles of confounding, lattice and cubic lattice designs, balanced incomplete blocks, lattice squares, and Youden squares.

With the spread of quality control, the engineer has become increasingly familiar with randomized blocks, Latin squares and to some extent factorial experiments. However, as progress is made, the engineer will have considerable use for the less widely-known balanced incomplete block designs, lattice and cubic lattice designs, etc. In most experimental work it is generally necessary to divide the larger-scale experiments into "blocks" or subsidiary parts for test purposes in order that differences between blocks can be accounted for in case such discrepancies occur, and so that the accuracy of the experiment can be thereby increased. (The engineer will use the term "block" in his experiments to mean a day, several operators adjusting a single machine, a group of materials tested under the same conditions, etc.). In such cases the entire number of treatments, lots, types of material, etc., which are to be compared do not have to be tested simultaneously at one time on a single day, under essentially the same conditions, etc., provided the experiment is properly designed so that the statistical analysis of results can in effect eliminate differences which arise due to the different blocks or subsidiary parts of an experiment. Hence, the experimental designs with small block size will be not only very attractive to the engineer, but will become of great importance to him because of, for example, tool wear, non-reproducibility of test results from day to day, or "errors of the day" in measurement, limitations in test facilities, etc. All of the designs will be found useful in both destructive and non-destructive tests.

One of the vital problems facing the engineering field today has to do with the matter of inter-laboratory testing. Here contradictory results arise because of differences in location of and climatic conditions at the laboratories, different types of instrumentation, different operators, errors of the day, etc. There arise, therefore, many sources of variation or components of variance which could be handled simultaneously and treated effectively by appropriate experimental designs. As a matter of fact, it is not possible for many laboratories to attach accurate standard errors to their measurements because they have not conducted adequate investigations to estimate the different components of variation. Indeed, it would appear that systematic experiments carried out with all statistical validity would reduce to a minimum the many arguments which are now being engaged in by industrial personnel.

Although *Experimental Designs* is written mainly with the biological and agricultural fields as backgrounds, the engineer should experience no particular difficulty in translating the language and statistical content of the book to the jargon of his own field. The book is notable in that it contains precise treatments of many of the important aspects of scientific procedure which the engineer has long been in need of and which have been ignored altogether or considered too lightly in other books on design and analysis of experiments. In addition to the methods of statistical analysis, the assumptions underlying many of the designs and the analysis technique are given in some mathematical detail (although generally the engineer will not have to be vitally concerned with this, but could consult a statistician as necessary), the methods of randomization are emphasized and outlined, the important problem of treating missing data is covered along with each of the designs, consideration is given to the efficiency of the particular type of design, and formulae for the standard errors of the difference between two treatment or variety means are given for the various designs. Thus, all necessary and important details for an adequate analysis are covered and the formulae given can be depended on to be accurate.

It is for the above reasons that the reviewer regards this book as the only one which has appeared on design and analysis of scientific experiments that is more or less self-contained. That is to say, upon being faced with an experimental program, the engineer, based on his own knowledge of the experimental setup and his familiarity with the material involved, can very likely decide on the type of experimental design or procedure to employ. All he has to do, then, is open the book, pick out an appropriate plan (the experimental designs or plans are given at the end of each chapter), follow the suggested method of randomization in arranging the material for test into blocks, and proceed confidently with the experiment. Once the experiment has been com-

pleted, the methods of statistical analysis can be found in complete detail in the book, and the comparisons and conclusions established on a sound basis. It is easy, therefore, for the reader to see why the book can be used as a manual—nothing of importance connected with the experimental program and its subsequent analysis is left out. This approach should eliminate much of the confusion in test results which has plagued the engineer in the past.

Other than the praise indicated above, the reviewer should say he is somewhat disappointed to find that the treatment of components of variance is covered rather superficially in the book. Components of variance are of particular importance to the experimenter, and the engineering statistician is in dire need of them in research and development work to determine which aspects of a problem should be tackled next. To call for this additional treatment in the book may have lengthened it unduly and perhaps this is the reason for its omission. Also, the reviewer is somewhat at a loss to understand the reasons for omitting the significance levels of the common statistical tests of significance such as Student's t-test, Snedecor's F-test, etc., as these tables would only add a few pages and would have a definite place in a book of this type.

Finally, it is pointed out that the book is written around the assumption of one observation per "cell", which apparently covers practically all cases in agricultural and biological work. In a large number of cases the engineer will have two or more observations per cell; but he is in a fortunate position here as he can generally estimate the random error or residual variance directly.

Notwithstanding these latter comments, however, the reviewer recommends without reservation that *Experimental Designs* is *the* book for those engaged in experimental statistics. Cochran and Cox are to be congratulated and thanked for this outstanding achievement and the service they have rendered to those engaged in experimental work.

Bibliography

JOSEPH MOVSHIN, Editor

Assisted by the Editorial Committee, St. Louis Section, ASQC

On matters concerning the Bibliography Department, send correspondence, suggestions, and contributions to: Mr. Joseph Movshin, 9220 Old Bonhomme Road, St. Louis 24, Mo.

APPLICATION—ELECTRICAL INDUSTRY

QUALITY CONTROL IN TV RECEIVER PRODUCTION; L. Lutzker, Q.C. Engineer, Allen B. Dumont Laboratories, Inc.
(TV Engineering v. 1, n. 2, Feb. 1950, p. 6.)

Application of p and c charts, and sampling inspection, to the TV Receiver Mfg. Division. Setting up of inspection specifications and procedures, organization, and responsibilities for action are described. Illustrations and graphs.

QUALITY CONTROL-LIMIT CHARTING TECHNIQUES; L. Lutzker, (TV Engineering, v. 1, n. 7, July 1950, p. 16.)

This article discusses the need for quickly calculating control limits and gives fairly extensive tables for upper and lower limits for c charts.

APPLICATION—MEDICAL AND DRUG INDUSTRY

THE PRECISION OF THE U.S.P. ASSAY FOR PROTAMINE ZINC INSULIN; C. I. Bliss,
(Journal of the American Pharmaceutical Assoc., v. 38, n. 10, 1949, p. 560.)

Precision was tested by statistical analysis of parallel assays of 24 preparations of Protamine Zinc Insulin in different laboratories. Results: U.S.P. method is capable of finer distinctions than are required in practice.

A TURBIDIMETRIC METHOD FOR THE ASSAY OF STREPTOMYCIN AND ITS CRITICAL EVALUATION; Elizabeth J. Oswald and Lila F. Knudsen,
(Journal of the American Pharmaceutical Assoc., v. 39, n. 2, 1950, p. 61.)

A statistical analysis of the factors entering into the test is presented. Included are a nomograph and formula for the determination of the standard error of the assay.

APPLICATION—METALLURGICAL INDUSTRY

QUALITY CONTROL OF ALUMINUM ALLOY CASTINGS; Richard R. Senz, Aluminum Company of America, Cleveland, Ohio.
(The Foundry, v. 78, n. 7, July, 1950 p. 64.)

A discussion of the factors for control of quality under the following headings:

Design
Foundry practices
Inspection methods
Role of statistics

APPLICATION—MISCELLANEOUS

QUALITY CONTROL—A VALUABLE EMPLOYEE; Dr. J. H. Toulouse, Owens-Illinois Glass Co.
(Ceramic Industry, v. 54, n. 5, May 1950, p. 75.)

A brief history of quality control and an outline of some fields of application within an industry. (Receiving inspection, process control, and design of experiment).

QUALITY CONTROL OF CORRUGATED SHIPPING CASES FROM A BUYER'S VIEWPOINT; E. H. Balkema, Colgate-Palmolive-Peet Co., Jersey City, N. J.
(Tappi, v. 33, n. 5, May 1950, p. 26A.)

The PRACTICAL points of applying statistics to technology

TECHNOLOGICAL APPLICATIONS of STATISTICS

By L. H. C. TIPPETT, *British Cotton Industry Research Association*

". . . the testimonial of an authority who has had very broad experience in the application of statistics in research, development, production and inspection."
—*Walter A. Shewhart*

The author covers the various statistical methods that can be used . . . how they are used . . . the logic of their application to diverse technological problems . . . the practical importance of the mathematical assumptions involved.

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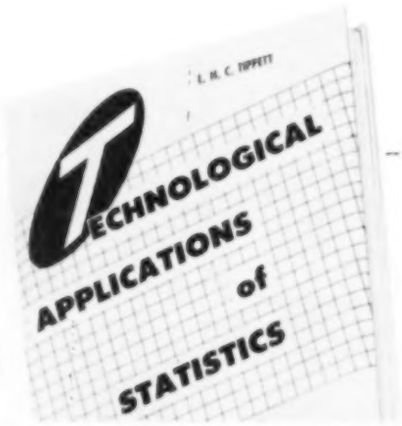

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A presentation of the problems likely to be met in controlling the quality of shipping cases. Not much statistics, but this article does give a clear picture of the need for close cooperation between buyer and vendor.

CONTROLLING CONTAINER QUALITY; G. A. Farrah, Technical Director, National Container Corp., Long Island City, N. Y.

(Tappi, v. 33, n. 5, May 1950, p. 32A.)

A general discussion of the long series of controls necessary to produce satisfactory containers. The author stresses the need for clear specifications, good testing facilities, and a responsible attitude for good quality on the part of all concerned.

ENGINEERING AND EXPERIMENTS

PRACTICAL ENGINEERING USES OF PROBABILITY PAPER—Part II; A. Boyajian, G. E. Company, Pittsfield, Mass.

(General Electric Review, v. 53, n. 7, July 1950, p. 41.)

Part I of this paper, in the June 1950 issue of the General Electric Review, was listed in the September IQC bibliography. Part II concludes the discussion on the use of probability paper for the analysis of distributions. Contains a table of probability integrals, with illustrations of its use.

DISCUSSION ON "THE STATISTICAL PART IN WELDING INVESTIGATIONS"; N. L. Navarre & W. E. Clautice.

(The Welding Journal, v. 29, n. 9, May 1950, p. 262-s.)

Mr. Navarre and Mr. Clautice describe an application of statistical planning of laboratory tests by a method of randomizing factors. This is an application of the material covered in the article "The Statistical Part in Welding Investigation" by B. B. Day in the Welding Journal v. 28, n. 10, Oct. 1949. This article was also reviewed in the May 1950 issue of IQC.

MANAGEMENT AND PERSONNEL

INCENTIVES FOR QUALITY; Prof. W. A. MacCrehan, Jr., Dept. of Administrative Engineering, New York University.

(Advanced Management, v. 15, n. 4, April 1950, p. 8.)

A short discussion of incentive plans for inspectors and standards by which inspection efficiency can be measured.

MISCELLANEOUS

OPERATIONAL ASPECTS OF INSTRUMENT DESIGN; Churchill Eisenhart, Chief, Statistical Engineering Laboratory, National Bureau of Standards, Washington, D. C.

(Science, v. 110, n. 2858, Oct. 7, 1949, p. 343.)

This is not directly an article on Statistical Quality Control, but it is of practical importance to every quality control man who gets his data from measuring instruments.

Mr. Eisenhart points out the tendency to place unquestioning trust in our instruments, and suggests that while this may be justified in the case of time tried designs, it is not always warranted in the case of new designs or where unusual conditions prevail. He illustrates his point with reference to auto-

matic sights for aircraft use in World War II, and to optical range finders. Errors due to external causes, and to the physiological and psychological limitations of the human operator are discussed. It is only when such factors are fully considered by both designer and user that modern instruments can serve their full purpose.

SAMPLING PLANS AND RELATED TOPICS

THE THEORY OF SAMPLING INSPECTION PLANS; H. C. Hamaker,

(Philips Technical Review, v. 11, n. 9, March 1950, p. 260.)

Second in a series of three articles. A technical review and comparison of the different sampling-inspection systems. Details of the mathematical expression of the operating characteristics of sampling plans are discussed. Use of average sample size and efficiency curves also noted. The first of this series is "Lot Inspection of Sampling" by H. C. Hamaker, in Philips Technical Review, v. 11, n. 6, Dec. 1949, p. 176.

THE PRACTICAL APPLICATION OF SAMPLING INSPECTION PLANS AND TABLES; H. C. Hamaker, J. J. M. Taudin Chabot, and F. G. Willenze.

(Philips Technical Review, v. 11, n. 12, June 1950, p. 362.)

This article, last in a series of three, continues the discussion of the operating characteristics, etc. of sampling plans, by H. C. Hamaker in the March 1950 issue of Philips Technical Review. The "Philips Standard Sampling System" (SSS) is given. This consists of single and double sampling plans listed by lot size and "Point of Control." Point of Control may be defined as the point on the slope of the operating characteristic separating the "Good" from the "Bad" quality lots. Single sampling plans are for lots of 1,000 units or under. Double sampling for over 1,000 units in a lot.

SAMPLING IN RELATION TO SPECIFICATIONS CONCERNING DEGRADATION OF TEXTILE MATERIAL; H. P. Stout.

(Journal of the Textile Institute (Transactions), v. 41, n. 4, April 1950 p. T 145.)

Statistics and the risk concept in sampling is applied to the testing of textiles to sample for the degradation effects of packaging, contamination, treatment, etc. As such testing is destructive in nature, the problem of getting reasonable assurance without excessive costs in samples presents itself.

THEORY AND APPLICATION—GENERAL

LATIN AND YOUDEN SQUARES (Statistical Designs for Greater Precision); (The Technical News Bulletin of the National Bureau of Standards, v. 34, n. 5, May 1950, p. 69.)

The arrangement of experimental procedures and data to eliminate the effects of possible uncontrolled variables can do much to improve the reliability of any results. As the precision of measurements improves, this can be of increasing importance. Illustrations of such arrangements are given in the use of the Latin and Youden squares. Work in this field is being carried on by W. J. Youden, Statistical Engineering Laboratory, National Bureau of Standards.

MISUSE OF THE AVERAGE DEVIATION;

(The Technical News Bulletin of the National Bureau of Standards, v. 34, n. 1, January 1950.)

This article discusses the use of the average deviation and its value in giving an estimate of the precision of individual measurements. As the estimate of the average deviation will vary with, and depend upon, sample size, it does not give a reliable or comparable measure of the precisions.

STATISTICS

WHY STATISTICS? P. C. Mahalanobis, President, Indian Science Congress.

(Science & Culture, v. 15, n. 8, Feb. 1950. p. 1, Supplement.)

This was an address given at the 37th session of the Indian Science Congress at Poona, Jan. 2, 1950. In it the history and origin of much of modern statistics is presented along with some concepts used in quality control work. (Errors of Observations, Individual Variations, Concept of Random Samples, Statistical Sampling, etc.)

In a general way, statistics as applied to many fields and in many countries is reviewed, with emphasis on the political and sociological aspects thereof.

SCATTER CHART AS A PRACTICAL TOOL. A SIMPLE MEANS OF PRESENTING JOINT TWO-WAY INFLUENCE; J. V. Sturtevant,

(American Statistician, v. 4, June-July, 1950, p. 20.)

ON THE DETERMINATION OF OPTIMUM PROBABILITIES IN SAMPLING; M. H. Hansen and W. H. Hurwitz.

(Annals of Mathematical Statistics, v. 20, Sept. 1949, p. 426)

SPREAD OF MINIMA OF LARGE SAMPLES; B. McMillan.

(Annals of Mathematical Statistics, v. 20, Sept. 1949, p. 444)

TABLES OF SEQUENTIAL INSPECTION SCHEMES TO CONTROL FRACTION DEFECTIVE; F. J. Anscombe.

(Royal Statistical Society Journal, v. 112, 1949, p. 180)

ON ESTIMATING THE MEAN & STANDARD DEVIATION OF TRUNCATED NORMAL DISTRIBUTIONS; A. C. Cohen, Jr.

(American Statistical Association, Journal, v. 44, Dec. 1949, p. 518)

ON THE BEST CHOICE OF SAMPLE SIZES FOR A T-TEST WHEN THE RATIO OF VARIANCES IS KNOWN; E. Walsh.

(American Statistical Association, Journal, v. 44, Dec. 1949, p. 554)

1950 CONVENTION PAPERS

The Fifth Midwest Planning Committee has very generously turned over to the Society the remaining printed copies of the papers presented at the Milwaukee Convention. The Society is very pleased to have these papers to round out its collection of available literature, and herewith expresses its appreciation.

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AMERICAN SOCIETY NEWS

NOMINATING COMMITTEE

As provided by the Constitution this Committee consists of the Junior Past President and one Director appointed from each Region, such appointments to be made by the President.

The President having duly discharged his obligation in this regard, the Nominating Committee for 1950-51 is constituted as follows:

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This Committee has been charged with exercising its duties so as to comply with Constitutional requirements on submission of a slate of officers in ample time for publication as provided.

EXECUTIVE COMMITTEE 1950-51

New Regional Directors having been duly chosen to succeed all of those whose terms have expired, the Executive Committee of the Society for 1950-51 is now complete and is constituted as follows:

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Simon Collier, *Executive Secretary*

Ralph E. Wareham, *Junior Past President*

Alfred L. Davis, *Treasurer*

Mason E. Wescott, *Chairman, Editorial Board*

Dorian Shainin, *Regional Director—New England*

Besse B. Day, *Regional Director—Middle Atlantic*

O. Herbert Somers, *Regional Director—Northern*

Edward M. Schrock, *Regional Director—Central*

Raymond S. Saddoris, *Regional Director—Midwest*

Wyatt H. Lewis, *Regional Director—Western*

The new Executive Committee held its first meeting on Saturday and Sunday, August 12 and 13, in New York City. Important action taken at that meeting is reported below.

CONVENTION NEWS

The 1951 National Convention will be held in Cleveland on Wednesday and Thursday, May 23rd and 24th. General Convention headquarters will be Hotel Cleveland but activities will center around the Cleveland Public Auditorium. These facilities are recognized as among the finest in the country and should prove admirable for the type of convention which it has been our custom to hold.

The large main Arena will provide both exhibit space and dining area. The Fifth ASQC Convention Committee has laid out an exhibit area comprising some sixty attractively decorated booths and a dining area capable of providing seating capacity for fifteen hundred. Plans are well under way to make this, the first completely National Convention, the largest and most inviting one to date.

Excellent facilities for clinics, forums, and training sessions are available, permitting the simultaneous conducting of seven sessions. As a result of the continued strong demand for basic education in Quality Control procedures, your Program Committee has arranged for a sound educational program on fundamentals. In addition, there will be a comprehensive program of interest to as broad a field as practicable. Sessions of particular interest to the fields of Automotive, Aircraft, Chemical, Electronic, Steel, Rubber, Food and Drugs, Gaging and Inspection, Mathematical Statistics, Armed Services, etc., have been designed to cover a wide variety of phases and problems. Everyone, regardless of his interest or development level, will find a variety from which to select. More complete program details will appear in the January issue.

It is now time that you started laying your plans; obtain clearance from the "boss", save your pennies for the wife's new hat, and prepare to come to Cleveland to help build "TODAY'S FOUNDATION FOR TOMORROW'S REPUTATION."

The Society's General Convention Committee announces that the 1952 Convention will be in Syracuse and that Philadelphia will be host to the 1953 Convention.

"QUALITY CONTROL FAIR"

An innovation in Sectional meetings is the December meeting of the Toledo Section which is being publicized as a "Quality Control Fair." Replacing the components of the somewhat conventional meeting will be a large exhibit of the "tools and gadgets of Quality Control and how they work." Included under this category are such items as graph paper, calculating devices, educational aids, tools and gages, etc. Supplementing this, it is planned to have nearby manufacturers exhibit and explain how quality control procedures have aided them.

Attendance will be open, not only to Society members, but to all other technical societies by invitation, to the members of the Foreman's Club of Toledo, and to the representatives of manufacturing companies. This promises an extremely interesting evening for December 6, 1951, at the Macomber Vocational High School, 15th and Monroe Sts., Toledo, seven to ten o'clock.

BOARD OF DIRECTORS

The terms of office of Directors representing the following Sections expired on June 30, 1950: Buffalo, Chicago, Cincinnati, Dayton, Denver, Georgia, Greater Muskegon, Illinois, Iowa, Milwaukee, Muncie, Northeast Indiana, Pittsburgh, Rock River Valley, St. Louis, Southern Tier, Tennessee, Toledo, Toronto,

Washington. The term of office of a National Director is two years, the terms of the Directors from half of the Sections expiring each year. Those Sections have now chosen their Directors to represent them for the period ending June 30, 1952, and the Board is therefore constituted as follows:

President: Wade R. Weaver
Vice-President: Martin A. Brumbaugh
Secretary: Simon Collier
Treasurer: Alfred L. Davis
Jr. Past President: Ralph E. Wareham
Chairman, Editorial Board: Mason E. Wescott

NEW ENGLAND REGION

Boston: Leonard A. Seder
Hartford: Dorian Shainin
New Hampshire: Herman D. Edgerly
Rhode Island: Roy K. Volkman
So. Connecticut: Welton D. Parker
Western Mass.: Gerald H. Cassady

MIDDLE ATLANTIC REGION

Baltimore: Besse B. Day
Delaware: Joseph R. Nixon, Jr.
Metropolitan, N. Y.: Eugene H. MacNiece
Philadelphia: Robert S. Inglis
Washington, D. C.: Churchill Eisenhart

NORTHERN REGION

Buffalo: Wilbur L. Burns
Mid-Hudson: O. H. Somers
Montreal, Que.: B. H. Lloyd
Rochester: Halsey H. Kent
Southern Tier: I. Glenn Stevenson
Syracuse: Joseph R. Sadowski
Toronto, Ont.: R. J. D. Gillies

CENTRAL REGION

Cincinnati: Maurice Rosenblatt
Columbus: Warner C. Nethero
Dayton: Max Astrachan
Erie: Edward M. Schrock
Georgia: Ralph A. Hefner
Michigan: Leo R. Harrington
Greater Muskegon: Charles A. Lutrey
Ohio: Stephen C. Bates
Pittsburgh: H. L. Springer
Tennessee: Thomas R. Bainbridge
Toledo: Nelson G. Meagley

MIDWEST REGION

Chicago: Henry J. Becker
Denver: Dale L. Lobsinger
Illinois: A. C. Richmond
Indianapolis: George W. McDermott
Iowa: Frederick J. Halton, Jr.
Milwaukee: Raymond S. Saddoris
Minnesota: Guy G. Parkin
Munice: James W. Fodrea
N. E. Indiana: Richard D. Long
Rock River Valley: C. A. Samuelson
St. Louis: Kort K. Pfabe
South Texas: T. L. Noel

WESTERN REGION

California: Wyatt H. Lewis
San Francisco Bay Area: Eugene L. Grant

EXECUTIVE COMMITTEE MEETS

The President gave a report of his activities since assuming office July 1st, and presented for approval by the Committee his appointments to the various Society committees.

The Montreal Section was accepted as the 43rd Section of the Society and placed in the Northern Region. The Secretary reported on increased activity toward the formation of further new Sections in the following areas: Evansville, Ind., Parkersburg, W. Va., Schenectady, North Carolina, New Mexico, and Seattle, Washington. Not only are 1950-51 dues being received in a gratifying manner, but also new memberships continue to come in most encouragingly.

A complete revision in the Society General Information Folder was presented, discussed and accepted; this new Folder should be available to all Sections very shortly.

Plans for increasing the size of *Industrial Quality Control* from a standard 32 page issue to 40 pages were presented. This means an increase of about 30% in the budget for publications. Complete details were also presented on the Second Class Mailing Permit for which the Society has applied. This will ultimately materially reduce the distributional expense of IQC. The September issue was the first to be mailed under this new system. Other steps in the direction of an improved magazine, with increased economies proportionately, were discussed and plans made to implement them.

The Fifth ASQC Convention Committee was made the Society's agent to conduct the 1951 Convention in Cleveland. A general plan for policy at National levels on Conventions was agreed upon and from now on National Conventions are to be truly National in character. The Society's General Convention Committee will be fortified by the addition of other members and this group will serve to guide the local committees and assist particularly on the subjects of exhibits, programming and finance.

The formal petition of the Philadelphia Section was accepted, and the 1953 Convention was allocated to that Section, with the understanding that assistance and cooperation was to be afforded by the other Middle Atlantic Region Sections.

The President's budget, expressing an anticipated income total of $31,245 and anticipated expenses totaling $29,150, was presented and accepted. Total expense of publications, as depicted by this budget, has been increased to $4.44 per member. An accompanying decrease in the National Offices operating cost to $2.97 per member puts this figure at its lowest since 1946-47. A proposal to further reduce the total of this latter cost by about $1,000 per year was presented and a committee appointed to study it further.

The Secretary reported that the Society membership total at the end of the fiscal year June 30, 1950, was 3,510. There were also 305 institutional subscribers to IQC. As of August 11, 1950, we had received an

additional 78 new members and 14 new institutional subscriptions.

It was reported that 30 of the 42 Sections had availed themselves of the National Office billing service. Of this number, 18 had adopted the standard recommended $4.00 local Section dues for all grades of membership, thus making it possible for the bills to be sent to the individual members direct from the National Office. It is recommended that Sections which have not yet adopted these standard dues give serious consideration to doing so this year. Such action will lead toward greater economies all around.

Minutes of the Board of Directors meeting at Milwaukee, June 3, 1950, were distributed to the Regional Directors, one copy for each Section in their respective Regions, so that they might be distributed to the various Directors under a covering letter from the Regional Director.

The Constitution and By-Laws Committee is presently engaged in incorporating in the Constitution the changes approved by the membership at the Annual Meeting in Milwaukee, June 2, 1950.

COMMITTEE APPOINTMENTS

The President announces the following appointments to General and Special Committees:

Robert E. Wagenhals, (Columbus Section), Timken Roller Bearing Co., Canton, Ohio, as Vice-Chairman of the Advertising Committee.

Professor John A. Henry (Illinois Section), University of Illinois, Urbana, Illinois, as Vice-Chairman of the Committee on Education and Training.

Eugene H. MacNiece (Metropolitan Section), Johnson & Johnson Co., New Brunswick, New Jersey, as General Chairman of the Publicity and Public Relations Committee.

Dr. Julian H. Toulouse (Toledo Section), Owens-Illinois Glass Co., Toledo, Ohio, as General Chairman of the Committee on Relations With Other Technical Societies.

Robert S. Inglis (Philadelphia Section), General Electric Co., as General Chairman of the Membership Committee.

Roland H. Noel, Chairman of the Chemical Technical Committee, announces the appointment of the following additional members to his Committee:

E. C. Harrington, Jr. (Western Mass. Section), Monsanto Chemical Co., Springfield, Massachusetts.

Frank E. Satterthwaite (So. Connecticut Section), General Electric Co., Plastics Division, Pittsfield, Massachusetts. This important Committee is swinging into action and has considerable activity lined up.

Dorian Shainin, Chairman of the newly formed Aircraft Technical Committee, announces the following additional appointments:

Dale L. Lobsinger (Denver Section), United Airlines, Denver, Colorado.

John J. Riordan (Dayton Section), Quality Control Division, Wright-Patterson Air Force Base, Dayton, Ohio.

SHEWHART MEDAL COMMITTEE

In accordance with the rotational plan set up by this Committee, the terms of service of three of its members expired June 30, 1950. The Society herewith expresses its appreciation for loyal service to:

Philip L. Alger, General Electric Company
Ernest L. Fay, Deere & Company
Charles A. Bicking, Hercules Powder Company

The President has appointed Warren R. Purcell as Chairman of the Committee, to succeed Mr. Alger, and the following to serve a three year term expiring June 30, 1953:

Lloyd A. Knowler, University of Iowa
Eugene L. Grant, Stanford University
Leslie E. Simon, Ordnance Department, U. S. A.

Completing the Committee of nine are:

Andrew I. Peterson
G. Rupert Gause
J. Frederick Verigan
Warren R. Purcell
Charles E. Stines
Paul A. Robert

The Shewhart Medal is awarded each year to an individual noted for outstanding leadership in the field of modern quality control. To select the 1950 Medalist, the Shewhart Medal Committee has been fully organized and activated, according to announcement by W. R. Purcell, Chairman.

Members of the Society, groups of members, or Sections may submit nominations for 1950 Medalist. It is urged that nominees be selected on a broad national and international scope. Original pioneering in the field, successful promotion and management of quality control programs, and service to the art and to the Society are among the factors which should be considered in selecting nominees. Membership in the Society is not in itself a requirement for eligibility.

Nominations should be sent directly to W. R. Purcell at Brown Company, Berlin, New Hampshire. Nominations may be made at any time until the closing date of January 31, 1951. Supporting evidence, listing accomplishments, etc., should also be sent by the nominators, either at the time of the nomination or subsequently, but in any case for receipt not later than February 9, 1951.

The Shewhart Medal will be presented to the 1950 Medalist at the Cleveland Convention on May 23, 1951.

CONSULTING SERVICES

Responsibility of the American Society for Quality Control, Inc., for Consulting Services advertising is limited to certification that advertisers hold the grade of membership in the Society stated in their advertisements. Qualification requirements for the several grades of membership are set forth in the Constitution of the Society.

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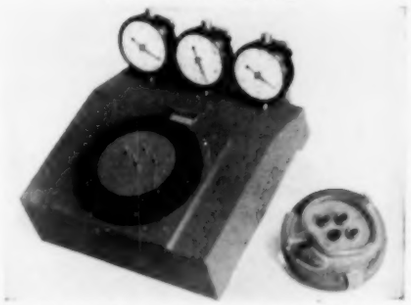

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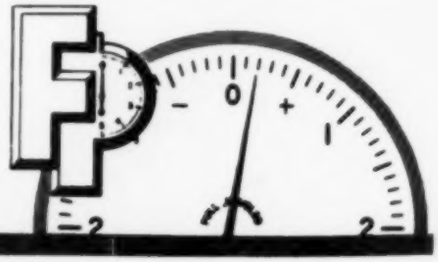
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